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STATUS OF SOME NEW HERBICIDES

U.S. Department of Agriculture
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SUMMARY

This paper reviews the past 15 years of research at Alexandria, Louisiana, on 10 of the newer herbicides that are in use or show promise. Only formulations with relatively high activity are included.

The report is based on more than 60 studies, including soil, foliar, and injection applications. The outlook is good for effective substitutes for herbicides now in use, and for new products that will control a broader array of species with greater consistency.

If herbicides are handled, applied, or disposed of improperly they may be injurious to humans, domestic animals, desirable plants, and pollinating insects, fish, or other wildlife, and may contaminate water supplies. Use herbicides only when needed and handle them with care. Follow the directions and heed all precautions on the container label.

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Status of Some New Herbicides

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Research to find more effective and less expensive methods of controlling cull hardwoods has been conducted continuously over the past three decades at Alexandria, Louisiana. Ammate in chopped cups, 2,4,5-T in frills, aerial spraying, and tree injection with undiluted herbicides are some of the innovations originating from this work that have saved landowners millions of dollars in site preparation, release, and stand improvement.

This paper summarizes the performance of 10 effective or promising herbicides that have been evaluated over the past 15 years at Alexandria. The information was obtained in about 60 studies, each of which tested two or more formulations. In all, about 30 formulations were evaluated, but many were ineffective or withdrawn by the manufacturer.

Only a few of the 10 herbicides are registered for specific uses in forestry; others are registered for nonforestry purposes, and several have no registration or only experimental registration. Data given here will aid in improving current practices and perhaps even in obtaining registrations.

Herbicides were tested for efficacy when applied to the foliage, to the soil, and injected into the base of trees. Some (such as pellets) were suitable only for soil application; most liquid formulations were tested by tree injection and foliar spraying. Procedures that were standard in tests are:

1. Tree injection incisions were made with a 1.75-inch bit within 2 inches of groundline. Spacing between incisions was measured from edge to edge.
2. Soil application consisted of uniformly distributing pellets, granules, or powders in a band 12 to 24 inches wide about 12 inches from tree base.
3. Foliar sprays were applied with backpack mist blower or garden sprayer.
4. Topkills were estimated two growing seasons after treatments were applied.

Herbicides are arranged alphabetically by common or trade names. The manufacturers of herbicides mentioned in this paper are listed in Appendix A. Since the text is restricted to highlights of the studies, detailed results of some of the more important studies are given in Appendix B. Publications emanating in whole or part from these studies are listed in Appendix C.

Many trials were made with mixtures of herbicides, of which only a few are mentioned. Also, about a dozen studies were conducted that attempted to combine soil and foliar herbicides (usually applied about 30 days apart). None of these are reported, although in several instances results obtained from application of one of the herbicides applied alone as a check have been used.

Throughout this paper the performance of herbicides is described in general terms like high or satisfactory, marginal, or unsatisfactory kills. Definitions for these terms vary by method of application. Generally, foliar sprays are satisfactory or effective if top defoliations are 75 percent or higher, marginal when between 60 and 74 percent, and unsatisfactory when below 60 percent. Criteria for kills with tree injection are slightly higher.

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Statistical tests were made in all comparisons, but they are not reported. Emphasis has been placed on overall efficacy rather than relative performance.

GLYPHOSATE

Glyphosate is a new herbicide that shows considerable promise. It has been tested in two water-soluble liquid formulations: (1) MON 2139, now registered as Roundup, containing 3 pounds acid equivalent (ae) per gallon with a surfactant, and (2) MON 0139 containing 4 pounds ae per gallon without the surfactant. MON 2139 has experimental registration for foliar spraying and tree injection of unwanted hardwoods on forest sites.

Tree Injection

In 1973 both formulations were tested by tree injection with blackjack oak[1] and sweetgum, 5 to 7 inches d.b.h. A 1-ml dose of undiluted herbicide was applied in May in three incisions about 6 inches apart. Topkills were 97 and 100 percent for the two formulations, an excellent result given the wide spacing of incisions. The control, 2,4-D amine[2] gave only 80-percent control.

Glyphosate (MON 0139) was compared with Tordon 101 on blackjack oak and sweetgum. Trees were injected with 2 ml of undiluted chemical in one and two incisions in winter and spring. Trees were grouped in two diameter classes—3.5 to 5.0 inches and 6.0 to 7.5 inches. Overall, glyphosate outperformed Tordon 101 and resulted in excellent kills with only four exceptions, three of which involved a single incision (Appendix B, table 1). A single injection of glyphosate was effective on all sizes of sweetgum in each season.

In another study, Glyphosate (MON 0139), Tordon 101, and Velpar were compared on sweetgum, blackjack oak, and hickory ranging from 5 to 9 inches d.b.h. Treatments were applied in May using 1 ml per incision with incisions spaced at 7-inch intervals. Glyphosate gave excellent kills, except with hickory, and was better overall than the other two herbicides (Appendix B, table 2). A 1:1 mixture of glyphosate and Tordon 101 gave higher kills than either herbicide alone, and was fairly effective on hickory.

In another injection study (Appendix B, table 3), 2 ml of undiluted glyphosate (MON 0139) injected in June with incisions 5 inches apart gave almost complete topkill of red and blackjack oaks. Glyphosate (MON 0139) mixed with equal parts of 2,4-D amine was superior to Tordon 101R and 2,4-D amine alone on sweetgum (Appendix B, table 4).

Glyphosate is an excellent herbicide for injection. More precise guidelines for use on upland species and prescriptions for bottomland species are needed. Mixtures of glyphosate and less costly herbicides should also be investigated.

Foliar Spray

As a foliar spray, Glyphosate (MON 0139) was initially tested on 4-year-old sweetgum, red oak, and green ash in a brush nursery. It was applied in May with 3 pounds ae in 10 gallons of water per acre. Topkills were satisfactory, except on red oak, and were comparable to or better than results with 2 pounds of 2,4,5-T[3] ester.

In a follow-up study in the brush nursery, 3 pounds ae of glyphosate (MON 0139) in 20 gallons of water killed sweetgum, red oak, and green ash more effectively than tebuthiuron (2 pounds active), 2,4,5-T (2 pounds active), or picloram (1 pound active)[4]

In the first field study, 2 pounds active of glyphosate (MON 0139) were compared with 2 pounds of 2,4,5-T ester, 2.54 pounds of Tordon 101, and 2.74 pounds of Tordon 101R in 20 gallons of water per acre. Treatments were applied in late May to mixed brush on an upland site. Topkills ranged from 73 to 79 percent for all formulations except Tordon 101R, which gave 65 percent control (Appendix B, table 5).

As a foliar spray glyphosate needs much more testing, particularly at different rates of application. Tests of this herbicide should use the MON 2139 formulation because it has an experimental registration. A defoamer is needed with glyphosate, especially when it is applied as a foliar spray.

KRENITE

Krenite is formulated as a liquid containing 4 pounds active ingredient (ai) per gallon that can be mixed with water. It is registered as a foliar spray for weed and brush control on industrial sites, tank farms, rights-of-way, and drainage ditches, and is reportedly safe to use around ponds and water supplies. The primary use of Krenite is to inhibit bud break in the spring. To inhibit bud break unwanted plants are drenched in the fall, 30 to 40 days before senescence. This method is especially good in recreational or scenic areas because aesthetically objectionable brownout of foliage is avoided. Fall-spray tests are underway, but results are not yet available.

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[1] Scientific names of species are given in Appendix D.

[2] 2,4-D is registered for control of broadleaf weeds and certain susceptible woody perennials on agricultural lands, rangelands and pastures as well as such noncrop areas as rights-of-way, drainage ditch banks and vacant lots.

[3] 2,4,5-T is registered for control of herbaceous and woody plants in forests, on rights-of-way, and on rangelands and pastures.

[4] Picloram is the active ingredient in Tordon 101, Tordon 101R, Tordon 10K, and Tordon 22K.

One study of Krenite applied by tree injection has been completed (Appendix B, table 3) and another is in its second year. When 4 ml of undiluted Krenite was injected in June and incisions spaced 5 inches apart, high kills of red and blackjack oaks 5 to 7 inches d.b.h. were obtained. However, Tordon 101, glyphosate (MON 0139), Velpar, and Garlon 3A (Dow M-3724) were equally effective at only 2 ml per incision.

In a current study, Tordon 101, glyphosate (MON 0139), Velpar, and Garlon 3A (Dow M-3724) are being compared. Red oak, blackjack oak, sweetgum, and hickory were injected with 1 and 2 ml of undiluted herbicide per incision as follows: trees 3 to 5 inches d.b.h. received one incision, trees 6 to 8 inches two incisions, and trees 9 to 11 inches three incisions. First-year results (which are not always reliable) indicate Krenite performs satisfactorily on all but hickory and it is as effective as the other formulations in the test, but it is slower acting than most herbicides used for tree injection. Available information seems to show that Krenite has more promise in southern forestry when injected than when sprayed.

TEBUTHIURON

Tebuthiuron was formulated in a variety of ways during its development, including small pellets containing 10, 20, 30, and 40 percent active ingredient, an 80-percent wettable powder marketed under the trade name Spike, and large (10-gram) pellets containing about 10, 20, and 30 percent active ingredient. Studies have been conducted with most of the formulations. Currently, only the 20-percent pellets and the 80-percent wettable powder are available. The wettable powder is registered for use around industrial sites, railway roadbeds, and tank farms. The 20-percent pellets have a permit for experimental use in controlling brush on range lands. Granules in 1- and 5-percent formulations are also registered for some industrial uses, but we have not tested them.

Tebuthiuron has been tested in 17 studies, starting in 1973, most often by soil application alone or in combination with foliar sprays. Several studies were conducted with the wettable powder. Because of the major changes in available formulations, only a few of the more important studies are summarized here.

Broadcast

Tebuthiuron showed promise from the first study in which it was included. Ten-percent ai pellets were compared with 10-percent bromacil (Hyvar X)[5] pellets in April when broadcast at 4, 8, and 12 pounds ai per acre. The 4-pound rate of tebuthiuron controlled a broad array of hardwoods (including oaks) well. The two high rates gave almost complete control. In contrast, all rates of bromacil achieved only marginal control, ranging from 63 to 81 percent, and several prevalent species were resistant (Appendix B, table 6).

When 10-percent pellets of tebuthiuron, Tordon 10K, and Velpar were broadcast in April, on an upland site, at 4 pounds per acre, tebuthiuron was most effective (Appendix B, table 7). Broadcast at 8 pounds per acre, Velpar and tebuthiuron were effective, and both were superior to Tordon 10K.

In another study, on an upland brushy site, tebuthiuron (10-percent pellets) and Tordon 10K were compared by broadcasting 6, 8, and 10 pounds ai per acre in March. Contrary to early findings, the 6-pound rate of tebuthiuron was unsatisfactory, although the two higher rates were effective. Tordon 10K was effective at all rates.

Several other studies on upland sites showed that an 8-pound-per-acre rate of tebuthiuron is required for satisfactory control. Some variation in effectiveness probably was caused by differences in upland soils. Lower dosages were effective on the sandier soils and higher rates were needed on heavier, finer-textured soils.

A study conducted on a bottomland site that compared tebuthiuron and Tordon 10K broadcast at 4 and 8 pounds (active) per acre showed Tordon 10K was more effective at both rates, but only the 8-pound rate was satisfactory. Since the high rate of tebuthiuron gave only a 68-percent kill, the minimum rate on these sites should be at least 10 pounds per acre.

Tebuthiuron is a potent soil herbicide when broadcast, equal or superior to bromacil and Tordon 10K. But because its persistence in the soil limits its utility, no further broadcast studies are planned.

Banding

Tebuthiuron was also evaluated as 10- and 40-percent pellets, by banding individual trees on a sandy loam soil in May. It was compared with Tordon 10K, Velpar, and a combination of Tordon 10K and tebuthiuron at rates of 0.5 and 1.0 gram (active) per inch of trunk diameter (Appendix B, table 8). Concentration of tebuthiuron pellets had no important influence on kills. The 1-gram rates gave 93 and 97 percent control of post oak, but only 35 and 50 percent control of hickory.

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[5] Hyvar X, whose active ingredient is bromacil, is registered for use on noncropland for nonselective weed and brush control and for selective control in certain crops.

Tebuthiuron does have merit for banding individual trees. Banding trials should be conducted at rates from 1 to 3 grams of active material per inch of diameter.

Tree Injection

Tebuthiuron was also evaluated by tree injection in three studies, but it was inferior to Tordon in all trials. The liquid for injection was made by adding 0.5 and 1.0 pound ai of the 80-percent wettable powder to 1 gallon of water, but since the powder does not dissolve in the carrier, its lethal action may be limited.

TORDON 101

Tordon 101 is registered for application by injection and when mixed with 2,4,5-T for foliar spraying. It has been on the market for about 10 years. It is a liquid containing 2 pounds ae of 2,4-D amine and 0.54 pound ae of picloram per gallon.

Tree Injection

Over the past 15 years, Tordon 101 has been included in 18 individual injection studies. Initially, it was compared with 2,4-D amine, the standard chemical used for tree injection when testing began. Several comparisons of Tordon 101 and 2,4-D amine have been made (Appendix B, tables 9 and 10). Later Tordon 101 was used as a standard for evaluating other herbicides.

Tordon 101 has killed as much or more unwanted vegetation as 2,4-D amine in all comparisons, regardless of season, species, or site. It is effective on species that are difficult to kill with 2,4-D amine, including sweetgum, hickory, swamp privet, ironwood, pecan, and red maple. Tordon 101 is most effective when applied in late summer and winter, unlike 2,4-D which is most effective in spring and early summer.

Soon after Tordon 101's effectiveness was demonstrated, tests were conducted to determine if one-incision doses of 4 to 5 ml would kill several prevalent oak species, 2 to 8 inches d.b.h. Single incisions were not consistently satisfactory, although Tordon 101 again outperformed 2,4-D. Two incisions of 5 ml each gave acceptable kills of oaks up to 7 inches d.b.h.

When comparing Tordon 101 and 2,4-D amine it should be recognized that the acid equivalents are not the same. Tordon 101 contains 2.54 pounds ae per gallon, while 2,4-D has 4.0 pounds. However, Tordon 101 is about three times more costly than 2,4-D.

Since Tordon 101 is more viscous than many other herbicides, the liquid flows slowly from the injector. This may be a problem, especially in winter but it can be circumvented by mixing the herbicide with equal parts of water and increasing the dosage proportionately.

On upland sites, a 1-ml dose of undiluted Tordon 101 in incisions spaced 5 inches apart is recommended in all seasons for trees 5 inches d.b.h. and larger. For smaller trees, a 1-ml dose in two incisions is adequate. Local tests should be conducted to see if a wider spacing of incisions can be used in the dormant season. On bottomland sites, 1 ml in incisions 3 inches apart is recommended.

Foliar Spray

We have not adequately tested Tordon 101 as a foliar spray. In studies conducted in the brush nursery with high-volume applications, it showed no superiority over 2,4,5-T ester. In a field test with mixed species of brush, it gave marginal kills comparable to those achieved with 2,4,5-T. Little emphasis was placed on foliar-spray studies of Tordon 101 because early test results showed it had no superiority over 2,4,5-T alone and priority was given to a mixture of picloram and 2,4,5-T. Newer, more promising foliar sprays that have been tested in the last few years have shown this to be a valid decision.

TORDON 101R

Tordon 101R, also a liquid, has about one-half the concentration of each active ingredient as Tordon 101, a total of 1.37 pounds ae per gallon. It is registered for application by tree injection and frilling, but not as a foliar spray. The manufacturer states it is ready to use and gives no instructions for dilution. It is comparable to Tordon 101 mixed 1:1 with water, because it is less viscous, and flows quickly from an injector.

Tree Injection

In the first test of this formulation, May injection of 1 ml of undiluted chemical with incisions 5 inches apart resulted in 92 percent kill of red oaks 4 to 12 inches d.b.h. The same treatment with undiluted 2,4-D amine gave 99 percent kill. Defoliation of sweetgum with a 1-ml dose in incisions at 3-inch intervals averaged 51 percent for Tordon 101R and 67 percent for 2,4-D amine. Apparently, the concentration of this material is too low for 1-ml doses at wide spacing to be effective.

Until additional information is available from several studies that are underway, it seems advisable to rely on experience with Tordon 101 and use a 2-ml dose at 5-inch intervals.

Foliar Spray

Only one foliar spray study of Tordon 101R has been conducted. It compared 2.74 pounds ae or 2 gallons of Tordon 101R to 2 pounds ae of 2,4,5-T ester per acre. Both herbicides were mixed with water and applied in May at a rate of 20 gallons per acre. Topkill averaged 76 percent for 2,4,5-T and 65 percent for Tordon 101R. In the same study, Tordon 101 applied at 2.54 pounds per acre effected 75 percent topkill. It appears that both Tordon formulations are about as effective as the standard spray treatment with 2,4,5-T ester, and they may be adequate substitutes for 2,4,5-T. But they should not be used for pine release because conifers are highly sensitive to picloram.

TORDON 155

This is a liquid, oil-soluble formulation containing 4.0 pounds ae of 2,4,5-T ester and 1.0 pound ae of picloram per gallon. It is registered as a basal-bark and dormant-season top spray. It has, however, been evaluated by tree injection and as a spring-applied foliar spray.

Foliar Spray

The first foliar-spray test was started in 1964. A locally mixed formulation of Tordon 155 was applied in May at 2.5 pounds (0.5 gallon) per acre in a drench spray to a stand of dense brush. A 2.0-pound-per-acre spray of 2,4,5-T ester was used for comparison. Both formulations used oil as the carrier and both were about equally effective, killing over 85 percent of the hardwoods.

In 1971, the manufacturer furnished several combinations of herbicides for test. A formulation equivalent to Tordon 155 was sprayed on small, mixed brush at 2.5 pounds per acre in 10 gallons of oil and compared to 4.0 pounds per acre of 2,4,5-T ester. Topkills averaged 74 and 72 percent, respectively. Tordon 155 excelled on red maple, 2,4,5-T was most effective on dogwood, and they were equally effective on the other species.

Included in the same trial was a mixture of 2,4,5-T and picloram that was similar to Tordon 155. It had 4.0 pounds of 2,4,5-T ester and 0.75 pound of picloram per gallon, not quite as much picloram as a gallon of Tordon 155. It was applied like the other formulations at a rate of 4.75 pounds per acre. Overall, topkills from this formulation were slightly higher than from 4.0 pounds of 2,4,5-T ester alone (Appendix B, table 11).

Another study compared Tordon 155 and 2,4,5-T ester as top sprays in January or foliar sprays in June at rates of 3.0 and 6.0 pounds in 30 gallons of diesel oil per acre. All treatments resulted in satisfactory topkills, ranging from 79 to 91 percent in winter and 87 to 94 percent in summer. Differences between the two herbicides were small and unimportant in both seasons. The high rate of 2,4,5-T was no more effective than the low one; doubling the rate of Tordon 155 increased topkills about 12 percentage points, which hardly justifies the added cost (Appendix B, table 12).

Studies conducted so far indicate that as a foliar spray, Tordon 155 may be slightly more effective than 2,4,5-T when total pounds of active ingredient are the same, but the higher cost (about double)[6] of Tordon 155 and the need for oil in the mixture may easily offset the small advantage Tordon 155 may have.

Tree Injection

Tordon 155 has been evaluated by tree injection in three studies. In the first, the Tordon formulation was mixed 1:1 with oil and injected in red maple and sweetbay with 1 and 2 ml in incisions at 1-, 3-, and 5-inch intervals. (Mixing with oil in this ratio reduced the acid equivalent from 5.0 to 2.5 pounds per gallon.) The control, 2,4-D amine, was injected undiluted. Treatments were applied in April to trees 4 to 8 inches d.b.h. Both herbicides gave excellent kills of sweetbay, even at the widest spacing of incisions. 2,4-D failed badly on red maple, but Tordon 155 gave an 89-percent kill even at the widest intervals. Adding a small amount of picloram to 2,4,5-T (as well as to 2,4-D) seems to increase its activity on hard-to-kill species.

The next study compared Tordon 155 mixed 1:1 with oil to Tordon 101 and oil-soluble 2,4-D amine (3 pounds ae/gallon), on 4- to 8-inch blackjack oak, post oak, and hickory. One-ml doses were applied in one and two incisions per tree in May and December. None of the May treatments were fully satisfactory. Tordon 101 and Tordon 155 gave comparable kills and both were better than 2,4-D. Winter applications of both Tordon 155 and 2,4-D were far inferior to Tordon 101, which effected satisfactory topkills with two incisions (Appendix B, table 10).

Finally, Tordon 155 and undiluted 2,4-D amine were compared on blackjack and red oaks ranging from 5 to 7 inches d.b.h. Treatments were applied in May with one incision per tree and dosages of 2, 3, and 5 ml. No treatment gave satisfactory topkills (41 to 72 percent) and differences between herbicides were small.

When injected, Tordon 155 seems less effective than Tordon 101, but slightly superior to 2,4-D amine.

TORDON 10K

Tordon 10K is a pelleted herbicide containing 11.6 percent picloram (or 10.0 percent ae) as the active ingredient. It is registered for use in forestry by banding individual trees and broadcasting.

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[6] Costs vary by manufacturer and quantities purchased, making comparisons difficult.

Banding

Tests of Tordon 10K as a soil herbicide were started in 1962 by banding individual trees. The control was Hyvar X (as a wettable powder containing 80 percent ai), the most effective soil herbicide at that time. Test species were red and blackjack oaks on a sandy loam soil, and sweetgum and ironwood on a silt loam soil, 4 to 9 inches d.b.h. Both herbicides were applied in April at 0.25, 0.5, and 1 gram (active) per inch of trunk diameter. Tordon was satisfactory on ironwood at the two high rates and on sweetgum at all rates. Both oaks were resistant to Tordon 10K. Hyvar X was effective on blackjack oak and sweetgum at the lowest rate, but was unsatisfactory on the other two species at the highest rate. Overall, both herbicides were about equally effective.

Red oak, sweetgum, and ironwood from 4 to 12 inches d.b.h. were banded in March with the same two herbicides at 1.0, 1.5, and 2.0 grams per inch of diameter. The site was a low terrace with a silty clay soil. Kills, even at the 2-gram rate of Tordon, were very low on all species. In contrast, Hyvar X gave satisfactory kills of sweetgum and red oak at the 1.5-gram rate, but was ineffective with ironwood at all rates.

A study installed in May (ordinarily too late for maximum effectiveness) compared Tordon 10K, tebuthiuron pellets, and Velpar 90 percent water-soluble powder at 0.5- and 1-gram rates for each inch of trunk diameter. Test species were post oak and hickory 4 to 10 inches d.b.h. Tordon 10K was unsatisfactory on post oak and gave satisfactory kills of hickory only at the 1-gram rate. The other two herbicides were fully effective on post oak at the high rate. This study suggested Tordon may be a good candidate to mix with the other herbicides where hard-to-kill species like hickory are prevalent. Late application may have been a major factor in reducing Tordon's control of oak.

In a final banding study, Tordon 10K and 10-percent bromacil[7] pellets were compared on post and blackjack oaks 4 to 10 inches d.b.h. at 1 and 2 grams ai per inch of trunk diameter. Treatments were applied in March, April, May, and June. Tordon was unsatisfactory in all months at both rates, but bromacil was acceptable except at the 1-gram rate in June. The high resistance of oaks to Tordon 10K was clearly demonstrated in this study.

Banding is ideally suited for small tracts where hardwoods are 4 inches d.b.h. or larger, especially when the landowner doesn't want to inject trees. In such cases, Tordon 10K is useful, especially on sandier soils. It should be applied at a minimum of 1.5 grams per inch of trunk diameter; more for oaks or when treatin finer-textured soils. As with all soil herbicides, applica tions should be made in March or April when rainfa is high. Hyvar X is an excellent soil herbicide, but pow der is difficult to apply.

Broadcasting

Tordon 10K was also tested for broadcasting, agai using 10 percent bromacil pellets for comparison. Bot herbicides were broadcast in March at rates of 2.5, 5. and 7.5 pounds per acre. Plots, located on a poor drained upland site, had dense stands of small brus Kills were marginal at the high rate, averaging 73 pe cent for Tordon 10K and 66 percent for bromacil.

In a study designed to determine effects of litter o herbicide effectiveness, 2, 4, and 10 pounds of Tordo 10K were broadcast in March on plots with mixe brush 2 to 12 feet tall. The 10-pound rate gave 9 percent kill, compared to 73 and 56 percent for th two lower rates. No other herbicide was tested. Remo al of litter did not improve defoliation at any rate.

Tordon 10K and 10 percent tebuthiuron pelle were compared by broadcasting in March on a sand loam soil at 2, 4, and 6 pounds per acre. At the pound rate, Tordon 10K was satisfactory and mo effective than tebuthiuron. At the high rates, both he bicides were comparable. Unlike tebuthiuron, Tordo gave marginal kills of resistant oak.

Tordon 10K and 10-percent tebuthiuron pelle were also evaluated at 4- and 8-pound rates on creek-bottom site with small brush. Pellets were broa cast in May to avoid flooding. Kills averaged 89 pe cent for Tordon and 68 percent for tebuthiuron. To don was relatively ineffective on oaks, but was superi on most other species, the best performance of Tordo 10K to that time.

In a comparison of Tordon 10K and tebuthiuro pellets on an upland soil, pellets were broadcast March at 6, 8, and 10 pounds (active) per acre. Tordo was satisfactory at all rates, as was tebuthiuron at th two higher rates (Appendix B, table 13). A 1:1 mix the two herbicides was as effective as Tordon alone.

More recently, Tordon 10K, tebuthiuron, and Velp pellets, all with 10 percent active material, were com pared by broadcasting in April at 4 and 8 pounds p acre. The site had a sandy loam soil and dense har woods. Tordon ranked third in effectiveness at bot rates; tebuthiuron gave the highest kills (Appendix table 7).

Tordon 10K is an effective soil herbicide whe broadcast at 10 pounds (active) per acre. Like oth soil herbicides, it should be applied in late winter early spring when rains occur regularly. Why Tordo outperformed tebuthiuron in some studies and not others is unclear; it may have been due partly to the prevalence of oaks, which are resistant to Tordon. Resistance of oaks is a major disadvantage of this herbicide. Its greatest value may be in mixing with other herbicides that are lethal to oaks.

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[7] Bromacil is no longer available in pellet form.

TORDON 5K

This is a new, pelleted formulation that has about half as much picloram (the active ingredient) as Tordon 10K. The added weight is a decided drawback when broadcasting. If 10 pounds ai per acre is to be broadcast, 200 pounds of material must be distributed. But one potential advantage is rapid infiltration into the soil.

Tordon 5K and 10K have been compared in only one study. They were broadcast in May on an upland soil at a 6-pound rate. Topkills were 55 and 75 percent for the 5K and 10K formulations.

Additional studies are planned with Tordon 5K, but primarily as a banding treatment where weight is less critical than with broadcasting.

TRICLOPYR

Triclopyr, a relatively new herbicide, was initially made available for preliminary research in two formulations: M-3724, a water-soluble amine containing 3 pounds ae per gallon, and M-4021, an oil-soluble, water-emulsifiable ester containing 4 pounds ae per gallon. The amine formulation is now registered for foliar spraying and carries the trademark Garlon 3A Herbicide.

In our studies, the amine formulation has been used for tree injection and the ester formulation for foliar spraying, the same pattern that was followed with the phenoxy herbicides (2,4-D amine and 2,4,5-T ester).

Foliar Spray

Garlon 3A Herbicide was initially evaluated as a foliar spray in the hardwood brush nursery at 2 pounds ae in 20 gallons of water per acre. Trees were sprayed in May. Topkills of red oak were unacceptable and were marginal for sycamore and green ash. They were, however, comparable to those from 2 pounds per acre of 2,4,5-T ester.

As part of an evaluation of combined soil and foliar applications, Garlon 3A was sprayed on mixed brush in June at 1.5 pounds in 10 gallons of water per acre. Defoliation with Garlon 3A alone averaged 60 percent, which was promising, given the low concentration of the spray.

Triclopyr in its ester formulation (containing 4 pounds ae per gallon) was also appraised as a foliar spray on mixed brush. A rate of 2 pounds in 20 gallons of water per acre applied in May gave 79 percent topkill, comparable to that from 2 pounds of 2,4,5-T ester used as a check. When triclopyr (M-4021) was mixed 1:1 with 2,4,5-T ester (total 2 pounds active) or Tordon 101 (total 2.27 pounds active), defoliations were as high as with triclopyr alone (Appendix B, table 8).

Triclopyr (M-4021) was compared with 2,4,5-T ester as a foliar spray in January and June at 3 and 6 pounds in 30 gallons of oil per acre. Topkills from winter applications were excellent at both rates, and exceeded 2,4,5-T by 8 to 11 percentage points. Results from summer treatment were similar for both herbicides at the 3-pound rate, but triclopyr was more effective at the high rate (Appendix B, table 12).

Tree Injection

Triclopyr has not only shown promise as a foliar spray, but has given high kills when injected. A 2-ml dose of undiluted Garlon 3A (M-3724) applied in June with incisions 5 inches apart gave complete topkills of red and blackjack oaks. Undiluted Tordon 101, glyphosate, and Velpar at the same dosage were also highly effective (Appendix B, table 3).

In a follow-up study, a 1-ml dose of a 1:1 mixture of undiluted Garlon 3A and 2,4-D amine (total 3.5 pounds active) injected in May gave perfect kills of red oak with incisions 5 inches apart and 95 percent kill of sweetgum with incisions 3 inches apart. Tordon 101R and 2,4-D amine were about equally effective in 1-ml doses on red oak, and less effective on sweetgum, a species resistant to tree injection (Appendix B, table 4). Garlon 3A shows exceptional promise for application by tree injection.

Undiluted Garlon 3A is included in a comprehensive injection study still underway with red oak, blackjack oak, sweetgum, and hickory. Doses were applied in July at 1 and 2 ml of undiluted material per incision. Number of incisions varied with tree size: hardwoods 3 to 5 inches d.b.h. have one incision, trees 6 to 8 inches have two incisions, and trees 9 to 11 inches have three incisions. At the end of the first growing season, Garlon 3A and Tordon 101 both gave high kills of all species. Both triclophyr formulations show enough promise to merit additional research by tree injection and foliar spraying.

VELPAR

Tests have been conducted with hexazinone (the trade name of which is Velpar) formulated as a 90-percent ai water-soluble powder, 10 and 15 percent ai pellets, and a liquid containing 2 pounds ai per gallon. Only the powder is registered, and it is limited to spraying around industrial sites, rights-of-way, tank farms, and for weeding in Christmas tree and established conifer plantations.

Banding

In its initial evaluation, the 90-percent, water-soluble powder was compared to Tordon 10K, tebuthiuron, and a 1:1 mixture of Tordon 10K and tebuthiuron. In May, 4- to 10-inch d.b.h. post oak and hickory trees on a sandy loam soil were banded at rates of 0.5 and 1.0 gram ai per inch of tree diameter. Both rates of Velpar were effective on post oak, but gave low kills of hickory (Appendix B, table 8). No formulation was as effective as Velpar on post oak only the high rate of Tordon 10K alone or the Tordon-tebuthiuron mixture controlled hickory satisfactorily.

In a banding study on a sandy loam soil, Velpar applied in May at 1 gram active per inch of trunk diameter gave excellent results with blackjack oak but marginal results with red oak. Tebuthiuron and bromacil in the same study were as effective as Velpar on blackjack oak but unsatisfactory on red oak. Low kills overall were attributed to late applications.

Velpar appears to be an excellent herbicide for banding hardwoods. Ten-percent pellets are available for trials, and studies should be conducted using rates higher than 1 gram per inch of diameter.

Broadcasting

Broadcasting Velpar pellets has also given encouraging results. In a comparison of 10 percent pellets of Velpar, tebuthiuron, and Tordon 10K applied in April on an upland site at 4 and 8 pounds ai per acre, tebuthiuron was most effective at both rates and Velpar ranked second (Appendix B, table 7). Both herbicides controlled hardwoods satisfactorily, while Tordon 10K gave marginal kills.

Additional studies of soil-applied Velpar are needed on upland and bottomland sites to determine optimum rates and the minimum interval that must elapse between application and planting. Currently available data indicate Velpar does not persist in the soil long enough to affect planting survival when used for site preparation. Moreover, it controls herbaceous vegetation as well as woody plants.

Tree Injection

Velpar was evaluated for tree injection as the 90-percent powder before the liquid formulation became available. Four pounds (active) per gallon were mixed in water and injected in May at 1 ml in incisions 7 inches apart. Study trees were sweetgum, blackjack oak, and hickory, 5 to 9 inches d.b.h. Topkills were excellent with oak, intermediate with sweetgum, and very low with hickory. Undiluted Tordon 101 and glyphosate (MON 0139) were more effective than Velpar, especially on hickory (Appendix B, table 2). Spacing of incisions was wide, however, a severe test that probably contributed to the relatively low kills from all herbicides.

When the liquid formulation of Velpar (DPX-3674-L) became available it was compared with five other herbicides applied in June on red and blackjack oaks, 5 to 7 inches d.b.h. (Appendix B, table 3). All formulations effected high kills, except tebuthiuron, which was in wettable powder form.

A 1:1 mixture of Velpar and 2,4-D amine outperformed 2,4-D alone and Tordon 101R on sweetgum and did as well on red oak (Appendix B, table 4). Several other herbicide mixtures in the study gave kills of red oak in excess of 90 percent. On sweetgum, a resistant species, glyphosate (MON 0139), Velpar, tebuthiuron, and triclopyr (Garlon 3A) each mixed 1:1 by volume with 2,4-D amine gave satisfactory kills.

Liquid Velpar is an excellent candidate for tree injection. Its major drawback is ineffectiveness on hickory. Studies are underway to determine optimum dosages and incision spacing for upland and bottomland species.

Evaluations of Velpar for foliar spraying are not completed because the liquid formulation for such studies only became available during the last year. However, we intend to give high priority to foliar-spray studies.

DISCUSSION

Herbicides play a key role in managing pines and hardwoods in the South. As mechanical site preparation declines and more owners of small tracts intensify management practices, herbicides will probably grow in importance. The time is critical. Herbicides and other pesticides are under careful scrutiny for their impact on the environment and all of its living organisms.

The cost of developing, testing, and registering a new herbicide cannot be justified by forestry use alone. Ordinarily, most new formulations tested in our research have large anticipated or actual agricultural or other nonforestry uses. This means the basic toxological evaluations are completed, so registration for forestry is relatively easy after data on efficacy are obtained, provided there are no unique environmental problems and the manufacturer judges forestry use will be profitable.

Forest managers are now in a fairly good position regarding tree injection and site preparation. Substitute herbicides are available in the event one is withdrawn from the market. A substitute for 2,4,5-T or Silvex for pine release is needed, but there are new herbicides being tested that seem likely to be adequate.

Certainly new herbicides will be more costly than the phenoxy compounds in wide use today. This should not be an obstacle to conducting research. We can often expect greater efficiency for the higher price, and nonchemical alternatives to phenoxy herbicides are also very expensive.

2,4,5-T and Silvex[8] both primarily used as foliar sprays, are being examined by environmental officials. If they are banned, Tordon 101 may be used for site preparation; it is too toxic to pines for release application. Garlon 3A, triclopyr (M-4021), glyphosate, and possibly Velpar will be suitable for foliar spray once they are registered. Tests of these herbicides should be intensified to support any applications the manufacturers may submit.

2,4-D, like 2,4,5-T and Silvex, is a phenoxy herbicide, but it has not been suspected of containing a dangerous contaminant. A few years ago, it was the primary herbicide for tree injection. Recently, however, many landowners switched to Tordon 101 and Tordon 101R, both highly effective on a broad array of species, including those resistant to 2,4-D. Krenite, Velpar, glyphosate, and Garlon 3A also seem to be good candidates for tree injection, and will be given priority in future studies.

Soil herbicides are not used extensively in southern forestry because most products are expensive and their effectiveness is closely related to soil properties. Moreover, they must be applied in early spring when rainfall is high and trees are growing actively. Tordon 10K is effective on many hardwood species (excluding oaks) and dissipates fast enough for use in site preparation. Many of the other soil herbicides tested have persistence problems. Velpar is an exception; preliminary data indicate pines can be planted in the first winter after its application. It has an added advantage in that it kills many herbaceous plants that compete with pines in the first few years.

Applying soil herbicides in bands around individual trees shows promise, theoretically. Our tests have probably been too conservative; higher rates of application are needed for greater consistency.

Mixtures of herbicides to control a broader array of unwanted trees is an important approach to the hardwood problem that cannot be overlooked. Testing mixtures must be given high priority, even though it greatly expands the research workload, because early results have shown great potential benefits.

The prospect for more effective herbicides is good. Development of new formulations should be accelerated and registration should be coordinated more closely among manufacturers, researchers, and users.

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[8] Silvex is currently registered for use in forests for control of woody, herbaceous and aquatic plants. It is also registered for use on industrial sites, rights-of-way, in ponds, farmyards, pastures, rangeland, and in rice and sugar cane.

APPENDIX A

Manufacturers Furnishing Mentioned Herbicides

Glyphosate	Monsanto Company
Hyvar X (Bromacil)	E. I. DuPont DeNemours & Co.
Krenite	E. I. DuPont DeNemours & Co.
Tebuthiuron	Elanco Products Company
Tordon 101	Dow Chemical Company
Tordon 101R	Dow Chemical Company
Tordon 10K	Dow Chemical Company
Tordon 5K	Dow Chemical Company
Tordon 155	Dow Chemical Company
Triclopyr or Garlon 3A Herbicide	Dow Chemical Company
2,4-D and 2,4,5-T	Experimental samples obtained from a number of companies
Velpar	E. I. DuPont DeNemours & Co.

APPENDIX B

Tables

Table 1.—*Topkill of blackjack oak and sweetgum when injected with 2 ml of undiluted Tordon 101 and glyphosate in two seasons*

Herbicide	Active material per gallon	Incisions per tree	Tree size	Blackjack oak		Sweetgum	
				Winter	Spring	Winter	Spring
	Pounds	*Number*	*D.b.h.*	*Percent*			
Tordon 101	2.54	1	3.5-5.0	41	40	87	35
		2	3.5-5.0	64	85	98	90
		1	6.0-7.5	12	34	47	25
		2	6.0-7.5	31	57	73	42
Glyphosate (MON 0139)	4.0	1	3.5-5.0	55	92	100	100
		2	3.5-5.0	89	99	100	100
		1	6.0-7.5	45	61	94	98
		2	6.0-7.5	69	94	97	100

Table 2.—*Topkill of three common hardwoods when injected in May with 1 ml of undiluted herbicide in incisions 7 inches apart*

Herbicide	Active material per gallon	Species		
		Sweetgum	Blackjack oak	Hickory
	Pounds	*Percent*		
Tordon 101	2.54	79	97	76
Glyphosate (MON 0139)	4.0	100	99	63
Velpar	4.0	73	97	6
1:1 mix of Tordon 101 and glyphosate	1.27+2.0	100	98	82

Table 3.—*Topkill of two oak species 5 to 7 inches d.b.h. injected undiluted at 5-inch intervals in June*

Herbicide	Active material per gallon	Dose per incision	Topkill	
			Red oak	Blackjack oak
	Pounds	*Ml*	*Percent*	
Tordon 101	2.54	2	100	98
Glyphosate (MON 0139)	4.0	2	100	98
Krenite	4.0	4	89	99
Velpar (DPX-3674-L)	2.0	2	100	99
Triclopyr (Garlon 3A)	3.0	2	99	100
Tebuthiuron (80% WP)	3.0	4	86	90

Table 4.—*Topkill of red oak and sweetgum 4 to 12 inches d.b.h. injected with 1 ml per incision in May with several herbicides and mixtures*

Species and herbicide	Active material per gallon	Spacing of incisions	Topkill
	Pounds	*Inches*	*Percent*
Red oak			
2,4-D amine	4.0	5	99
Tordon 101R	1.37	5	92
1:1 mix of triclopyr (Garlon 3A) and 2,4-D amine	1.5+2.0	5	100
1:1 mix of Velpar DPX-3674-L and 2,4-D amine	1.0+2.0	5	100
1:1 mix of tebuthiuron and 2,4-D amine	1.5+2.0	5	97
1:1 mix of glyphosate (M-0139) and 2,4-D amine	2.0+2.0	5	100
Sweetgum			
2,4-D amine	4.0	3	67
Tordon 101R	1.37	3	51
1:1 mix of triclopyr (Garlon 3A) and 2,4-D amine	1.5+2.0	3	95
1:1 mix of Velpar DPX-3674-L and and 2,4-D amine	1.0+2.0	3	89
1:1 mix of tebuthiuron and 2,4-D amine	1.5+2.0	3	94
1:1 mix of glyphosate (M-0139) and 2,4-D amine	2.0+2.0	3	91

Table 5.—*Topkill of small hardwoods by foliar spraying nine herbicides and mixtures applied in water at 20 gallons per acre in May*

Herbicide	Active material per acre	Average topkill
	Pounds	*Percent*
2,4,5-T ester	2.0	76
Triclopyr M-4021	2.0	79
Tordon 101	2.54	75
Tordon 101R	2.74	65
Glyphosate (0139)	2.0	73
1:1 mix of 2,4,5-T ester + triclopyr (M-4021)	1.0+1.0	75
1:1 mix of 2,4,5-T ester + Tordon 101R	1.0+1.37	78
1:1 mix of 2,4,5-T ester + glyphosate (0139)	1.0+1.0	62
1:1 mix of triclopyr (M-4021) + Tordon 101	1.0+1.27	78

Table 6.—*Comparison of pelleted tebuthiuron and bromacil when broadcast in April at three rates on an upland site*

Herbicide and rates[1]	Topkill Post oak	Blackjack oak	Sumac	Tree sparkleberry	Dogwood	All species
	Percent					
Tebuthiuron						
4 pounds	99	81	98	—	100	91
8 pounds	—	98	100	100	100	98
12 pounds	100	100	100	—	100	99
Bromacil						
4 pounds	99	76	36	10	100	81
8 pounds	96	75	50	6	100	63
12 pounds	100	100	43	9	100	77

[1] Pellets contained 10 percent active material; rates based on active material per acre.

Table 7.—*Topkill of mixed hardwoods by broadcasting Tordon 10K, tebuthiuron, and Velpar pellets[1] on an upland soil at two rates in April*

Herbicide	Topkill 4 pounds	8 pounds
	Percent	
Tebuthiuron	91	96
Tordon 10K	70	78
Velpar	83	92

[1] All pellets contained 10 percent active material; rates are active material per acre.

Table 8.—*Topkill of post oak and hickory when four soil herbicides were applied in bands in May*

Herbicide	Active material per pound	Rate per inch of d.b.h.[1]	Topkill Post oak	Hickory
	Percent	*Grams*	*Percent*	
Tordon 10K—10% pellets	10	0.5	27	79
		1.0	30	90
Tebuthiuron - 10% pellets	10	0.5	45	15
		1.0	97	35
Tebuthiuron—40% pellets	40	0.5	66	30
		1.0	93	50
Velpar—90% powder	90	0.5	91	12
		1.0	100	42
1:1 mix of Tordon 10K and 10% tebuthiuron pellets	10	0.5	11	33
		1.0	11	87

[1] Active material.

Table 9.—*Selected comparisons of undiluted 2,4-D amine and Tordon 101 for controlling hardwoods 5 to 9 inches d.b.h. by tree injection*

Herbicide	Concentration (a.e./gal.)	Dosage/ incision	Spacing of incisions	Season applied	Topkill		
					Oak	Sweetgum	Hickory
	Lb.	*Ml.*	*Inches*			*Percent*	
2,4-D amine	4.0	1	5	Winter	83	–	42
		2	5	Winter	90	–	33
		1	7	Winter	66	–	18
		2	7	Winter	88	–	51
Tordon 101	2.54	1	5	Winter	100	–	92
		2	5	Winter	98	–	100
		1	7	Winter	99	–	100
		2	7	Winter	100	–	96
2,4-D amine	4.0	1	7	Winter	54	46	0
Tordon 101	2.54	1	7	Winter	97	100	94
		1	9	Winter	95	90	97
2,4-D amine	4.0	0.5	7	Spring	74	38	–
Tordon 101	2.54	0.5	7	Spring	92	81	–
2,4-D amine	4.0	2	Two incisions	Summer	99	–	–
		4	One incision	Summer	74		–
Tordon 101	2.54	2	Two incisions	Summer	100	–	–
		4	One incision	Summer	88	–	–
2,4-D amine	4.0	1	Two incisions	Summer	70	11	42
Tordon 101	2.54	1	Two incisions	Summer	100	74	54

Table 10.—*Topkill of three common upland hardwoods injected with 1 ml of undiluted 2,4-D amine, Tordon 101, and diluted Tordon 155 in May and December*

Season and herbicide	Active material per gallon	Incisions	Post oak	Blackjack oak	Hickory
	Lb.	*Number*	*Percent*		
May injection					
2,4-D amine[1]	3.0	1	28	37	21
		2	49	44	45
Tordon 101	2.54	1	28	45	35
		2	76	82	70
Tordon 155[2]	2.5	1	23	16	71
		2	75	57	76
December injection					
2,4-D amine[1]	3.0	1	11	31	18
		2	45	49	34
Tordon 101	2.54	1	78	64	66
		2	87	93	97
Tordon 155[2]	2.5	1	10	24	61
		2	26	66	90

[1] Oil-soluble formulation that has been as effective as water-soluble 2,4-D amine with 4 pounds (ae) per gallon.

[2] Tordon 155 diluted 1:1 with oil to reduce active ingredient per gallon.

Table 11.—*Topkill of six prevalent brush species when sprayed in May with 2,4,5-T ester, Tordon 155, and a mixture similar to Tordon 155 with 10 gallons of oil per acre*

Herbicide	Rate per acre (ae)	Blackjack oak	Sweetgum	Blackgum	Huckleberry	Dog wood	Red maple	Avg.
	Pounds	*Percent*						
2,4,5-T ester	4.0	50	97	93	55	91	60	74
Tordon 155	2.5	48	99	93	45	67	78	72
Formulation similar to Tordon 155	4.75	76	100	99	74	90	76	86

Table 12.—*Topkill of mixed hardwood brush with three herbicides applied at two rates in winter and summer using 30 gallons of oil per acre*

Season and herbicide	Active material per acre	Topkill
	Pounds	*Percent*
January		
2,4,5-T ester	3.0	84
	6.0	85
Triclopyr (M-4021)	3.0	92
	6.0	96
Tordon 155	3.0	79
	6.0	91
June		
2,4,5-T ester	3.0	87
	6.0	87
Triclopyr (M-4021)	3.0	85
	6.0	98
Tordon 155	3.0	83
	6.0	94

Table 13.—*Topkill of mixed, small hardwoods by broadcasting pellets of Tordon 10K, tebuthiuron, and an equal mixture of the two at three rates on an upland soil*

Herbicides	Active ingredient	Pounds (ai) per acre		
		6	8	10
	Percent			
Tordon 10K	10	86	95	92
Tebuthiuron	10	66	91	89
1:1 mix of Tordon 10K and tebuthiuron	10	83	94	94

APPENDIX C

Publications Emanating from Herbicide Studies in Alexandria, Louisiana

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1969. Herbicide mixtures promising for hardwood control by foliar spraying. Proc. South. Weed Sci. Soc. 22: 245-250.

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1977. Control of hardwoods with chemicals. *In* Proc. Site Prep. Workshop (West). Alexandria, La., April 27, 28, 1977. p. 11-15.

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1970. Banding soil herbicides not promising for hardwood control. Proc. South. Weed Sci. Soc. 23: 225-229

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APPENDIX D

Common and Scientific Names of Listed Species

Common name	Scientific name
Blackgum	*Nyssa sylvatica* Marsh.
Blackjack oak	*Quercus marilandica* Muenchh.
Dogwood	*Cornus florida* L.
Green ash	*Fraxinus pennsylvanica* Marsh.
Hickory	*Carya* sp.
Huckleberry	*Vaccinium* sp.
Ironwood	*Ostry virginiana* (Mill.) K. Koch
Pecan	*Carya illinoensis* (Wangenh.) K. Koch
Post oak	*Quercus stellata* Wangenh.
Red maple	*Acer rubrum* L.
Red oak	*Quercus falcata*
Sumac	*Rhus* sp.
Swamp privet	*Ligustrum* sp.
Sweetbay	*Magnolia virginiana* L.
Sweetgum	*Liquidambar styraciflua* L.
Sycamore	*Platanus occidentalis* L.
Tree sparkleberry	*Vaccinium arboreum* Marsh.

Mann, W. F., Jr. and M. J. Haynes.
1978. Status of some new herbicides. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-21, 18 p. South. For. Exp. Stn., New Orleans, La.

Summarizes 15 years of research on 10 herbicides that are now in use or show promise. The report is based on more than 60 studies, including soil, foliar, and injection applications.

Additional keywords: Hardwood control, tree injection, foliar spraying, soil application, banding herbicides, site preparation, release, weeding, stand improvement.

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Forest Service
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Selected Bibliography of the Clearwing Borers (Sesiidae) of the United States and Canada

J. D. SOLOMON
AND
M. E. DIX

Southern
Forest
Experiment
Station

SUMMARY

The larvae of Sesiidae bore in trunks, bark, stems, or roots of forest trees, shade and ornamental trees, fruit trees, vines, and other crops. Often they do considerable damage. Over the years much has been published on the clearwing borers; this bibliography attempts to cover the major works. The compilation is in alphabetical order by author and indexed to species to aid those interested in the literature concerning particular species.

1979

Selected Bibliography of the Clearwing Borers (Sesiidae) of the United States and Canada

J. D. SOLOMON AND M. E. DIX

Members of the family Sesiidae are generally referred to as clearwing borers because most bear a striking resemblance to bees and wasps and because the larvae bore in trunks, bark, stems, or roots of trees, shrubs, vines, and other plants.

Many species, because of the extensive damage they do by mining and tunneling, are important pests. Species in the genera *Paranthrene Hubner, Podosesia Moschler, Synanthedon Hubner,* and *Sesia* Fab. are particularly known for causing defects and degrade in timber species, mortality in shelterbelt and ornamental plantings, and cull in nurseries. If not controlled, *Synanthedon exitiosa* (Say) and *S. pictipes* (G. & R.) can destroy entire orchards of fruit trees. Several species in the genera *Vitacea* Engelhardt, *Melittia* Hubner, and *Pennsetia* Dehne cause serious losses to various crops.

Over the years, considerable material has been printed on the clearwing borers. Holloway, Childers, and Gentry (311) recently published a bibliography on *Synanthedon pictipes* and *S. exitiosa* containing 163 references. Duckworth and Eichlin (193) included numerous references in their recent paper on classification.

The selective compilation presented here is an outgrowth of research on the *Podosesia* borers in ash and *Paranthrene* borers in oaks and cottonwood. We made an attempt to include the major papers on Sesiidae, but some undoubtedly were missed. Although numerous short papers and notes were included, many were intentionally omitted.

The initial sources of references were our files and the various entomological, forestry, and agricultural periodicals. Other important sources were Biological Abstracts, Forestry Abstracts, Review of Applied Entomology, and the National Agricultural Library's reference service.

The bibliography is in alphabetical order by authors. An index to species and their synonyms is provided to aid those interested in pursuing the literature on particular species. The scientific names and the generic and specific combinations given with the citations are as they were presented in the particular reference. Refer to the species index for the current usage. The currently recognized valid species as presented by Duckworth and Eichlin (193) were used except that a new species later described by Purrington and Nielson (452) and one described by Duckworth and Eichlin (194) are included.

This bibliography is intended for use by entomologists, foresters, horticulturists, pest control operators, and others who wish to refer to the literature on the clearwing borers in the family Sesiidae.

Anyone beginning a study of the Sesiidae should see the papers by Beutenmuller, Duckworth and Eichlin, Edwards, Engelhardt, MacKay, and Riley.

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Classification and Evaluation of Forest Sites on the Southern Cumberland Plateau

Glendon W. Smalley

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Summary

This paper presents a comprehensive forest site classification system for the southern portion of the Cumberland Plateau in northern Alabama, northwest Georgia, and extreme south-central Tennessee. The system is based on physiography, geology, soils, topography, and vegetation. Twenty-one landtypes are described, and each landtype is evaluated in terms of productivity and desirability of selected pines and hardwoods for timber production. Also, each landtype is rated for five soil-related problems that can affect forest management operations.

Acknowledgments

I am indebted to my colleagues, past and present, for their scientific input, reviews, and stimulating discussions. I am also grateful to the soil scientists, silviculturists, and practicing foresters who have reviewed this guide.

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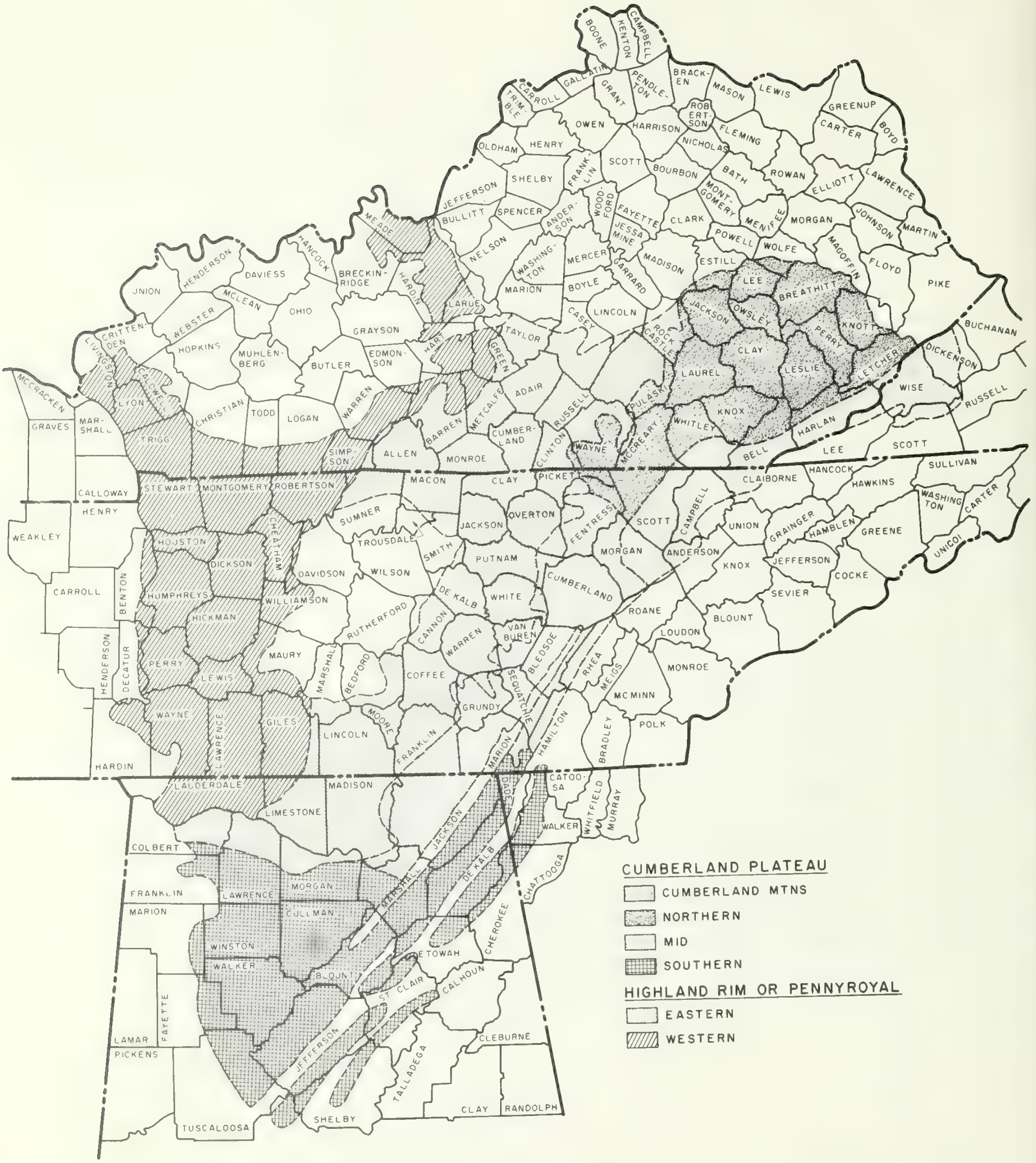

Figure 1. *Physiographic provinces and regions of the Interior Uplands.*

Classification and Evaluation of Forest Sites on the Southern Cumberland Plateau

GLENDON W. SMALLEY

Introduction

This report classifies and evaluates forest sites on the Southern Cumberland Plateau for the management of a number of commercially valuable tree species (fig. 1). It provides forest managers with a land classification system that will enable them to subdivide forest land into logical segments (landtypes) with about equal productivity, allow them to rate productivity, and alert them to any limitations and hazards that the landtypes impose on forest management activities. Though soils information is an integral part of this system, users will not need to identify and classify soils or to make laboratory determinations. This report is oriented to timber production because timber is usually a major management objective. However, there is no reason why landtypes cannot be the basis for interpretation for other forest resources.

I have drawn freely on much published information on geology, physiography, soils, sites, and yields. In many cases, data specific to this area were not available and information was extrapolated from adjacent regions. Extrapolation was particularly necessary with productivity data. All sources of data are documented so the user can gage the accuracy and reliability of the information.

Productivity and management problem information is presented in a format that follows the outline used by the Soil Conservation Service (SCS) in the Woodland Suitability sections of county soil surveys. This similarity should facilitate the integration of information contained in county soil surveys[1] into this classification system.

This guide represents the best information and collective judgment now available. Nevertheless, this guide is still incomplete. I trust that forest managers, after applying this site classification system, will share their experience with me and make me aware of any shortcomings or needed revisions.

Southern Cumberland Plateau Region

The Southern Cumberland Plateau (fig. 2) includes all of the Cumberland Plateau east and south of the Tennessee River. Covering all or portions of 18 counties in Alabama, 3 in Georgia, and 2 in Tennessee, it occupies about 8,900 square miles and extends south to north from about north latitude 33° 15′ to 35° 7′ and east to west from about west longitude 85° 20′ to 87° 50′. It extends southwest from Chattanooga, Tennessee, nearly to Tuscaloosa, Alabama, a distance of about 175 miles.

Included in the Region are such well-known landforms as the Warrior Coal Basin and Lookout, Sand and Little Mountains. Not included in the Region are the Moulton and Tennessee River Valleys, which are part of the Highland Rim, and the Sequatchie, Lookout, and Big Wills Valleys, which are part of the Ridge and Valley province.

Climate

The Region has a temperate climate characterized by long, moderately hot summers and short, mild winters. According to Thornthwaite's (1931) classification of climate, it is humid mesothermal. Tables 1 and 2 show average monthly and annual precipitation and temperature values, average frost-free periods,

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[1] See Appendix for available soil surveys.

Glendon Smalley is Principal Soil Scientist at the Silviculture Laboratory, maintained at Sewanee, Tennessee, by the Southern Forest Experiment Station, Forest Service-USDA, in cooperation with the University of the South.

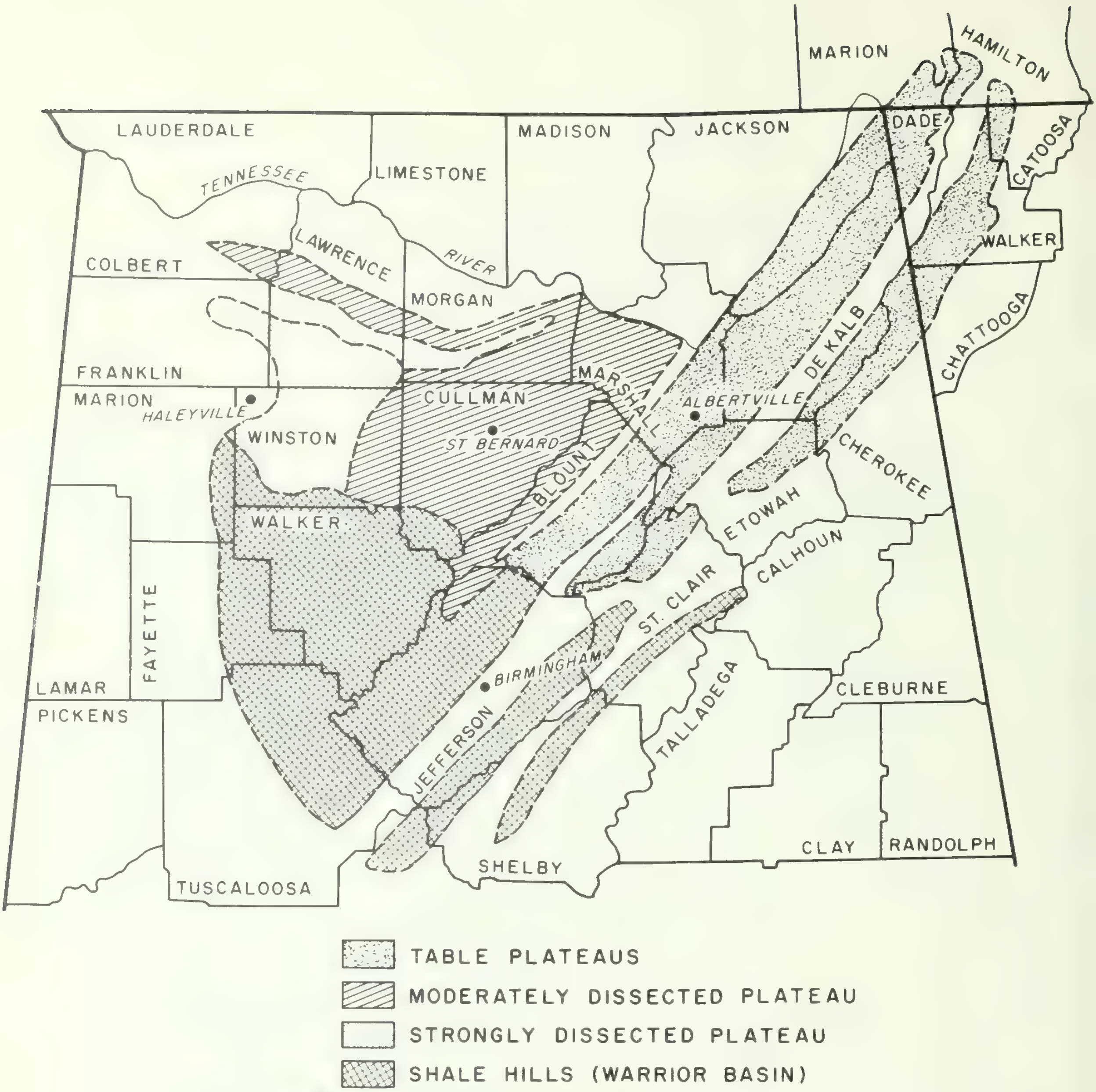

Figure 2. *Subregions of the Southern Cumberland Plateau and location of weather stations.*

and elevation above sea level for Albertville, Birmingham, Haleyville, and Saint Bernard (fig. 2). Albertville and Saint Bernard are the only stations on the Southern Plateau with long-term records of temperature and precipitation. Many stations like Haleyville and Birmingham have adequate records but are located off the Plateau in adjacent Highland Rim, Ridge and Valley, and Coastal Plain provinces.

Mean temperature for the Region is about 60°F. No long-term freeze data are available for Haleyville, but average date of last freeze is March 3 for Albertville, March 16 for Birmingham, and April 8 for Saint Bernard. Average date of first freeze is October 24 for Saint Bernard, November 6 for Albertville, and November 11 for Birmingham. Therefore, most of the Southern Plateau has an average frost-free period of 200 or more days. The temperature often falls below freezing at night in December, January, and February. The ground freezes 2 to 6 inches deep several times during the average winter season and commonly remains frozen for 2 to 10 days. Temperature does not vary much across the Region, but midafternoon temperatures in the summer may be 3 to 7 degrees cooler on the Plateau, particularly on Sand and Lookout Mountains, than in the adjacent valleys.

Table 1.—*Average monthly and annual precipitation in inches for four weather stations in northern Alabama.*[1]

Station and County	Years of Record	Elevation Ft	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Albertville Marshall, AL	51	1140	5.3	5.1	5.9	5.0	4.1	3.4	4.6	3.3	3.5	2.8	4.1	5.3	52.5
St. Bernard Cullman, AL	70	802	5.6	5.7	6.2	5.1	4.0	3.8	4.5	3.9	4.0	2.8	4.4	5.4	55.2
Birmingham Jefferson, AL	39	620	4.8	5.3	6.2	4.6	3.6	4.0	5.2	4.3	3.6	2.6	3.7	5.2	53.2
Haleyville Winston, AL	40	950	6.0	5.8	6.4	5.6	3.8	4.0	5.0	4.1	3.8	2.6	4.3	5.9	57.3

[1]U.S. Department of Commerce (1974).

Average wind velocity is low with southerly winds prevailing from May to September and northerly ones from November to March. Severe winds are infrequent and usually associated with summer thunderstorms.

Annual precipitation on the Plateau averages about 54 inches and ordinarily is fairly well distributed throughout the year. Precipitation is greatest from January through April. Least precipitation is from August through November. Short periods of very wet and very dry weather are common. Thunderstorms with high intensity rainfall are common in summer. Snowfall seldom exceeds a few inches and melts in a few days. Soils are wettest from December to April and driest from July to October. Tree growth is commonly retarded for periods of a few to several days up to six times each growing season.

Soil dryness during the growing season can also be shown by "frequency of drought days" data (Knetsch and Smallshaw, 1958). A drought day is a day when precipitation and evapotranspiration data indicate that soil moisture content is below the wilting point. Drought days are most likely in August when the probability of 10 drought days per month is 50 percent. The next highest probability of drought days is in July and September when the probability of 10

Table 2.—*Average monthly and annual temperature in °F and length of warm period for four weather stations in northern Alabama.*[1]

Station and County	Years of Record	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Warm Per.[2] Days
Albertville Marshall, AL	49	41	43	50	60	68	75	78	77	71	61	50	42	60	192
St. Bernard Cullman, AL	68	41	44	50	61	69	76	78	78	72	61	50	42	60	175
Birmingham Jefferson, AL	37	44	47	53	63	70	77	80	79	74	63	52	45	62	236
Haleyville Winston, AL	38	41	44	50	61	69	76	78	78	72	62	50	43	60	177

[1]U.S. Department of Commerce (1974).
[2]Mean period from last 32° F to first 32° F.

drought days per month is about 35 percent.

Geology, Topography, and Soils

In general the area is underlain by thick nearly horizontal beds of sandstone and shale, but in places only remnants of the old plateau surface remains (Fenneman, 1938). The highest elevations of the Southern Cumberland Plateau are on the northern end of Sand and Lookout Mountains, where the undulating surface averages 1,800 to 2,000 feet above sea level. Elevation of the Plateau declines southward at about 10 feet per mile. At the junction with the upper Coastal Plain, the Plateau averages 600 to 700 feet high.

The margins of Sand and Lookout Mountains have a conspicuous escarpment. South of the Tennessee River the escarpment is less conspicuous and faces north, and the Plateau top is 1,000 to 1,200 feet above sea level. As elevation declines, the sandstone caprock thins and is often cut through and sapped by drainages. Eventually, the caprock becomes so thin that the escarpment disappears.

Topography of the Southern Plateau varies from undulating to rugged and complex, and slope ranges from nearly level to steep. Relief is commonly 150 to 400 feet in the interior of the Plateau and is 1,000 feet or more at the escarpments bordering the Highland Rim and Ridge and Valley provinces.

Slope and topography affect the rate and amount of both surface runoff and subsurface movement of soil water. Soil loss by erosion increases as gradient and length of slope increase. Although rare under forested conditions, surface runoff is important during forest management operations. Soils on steep slopes are often shallower than soils on more nearly level terrain. Sediment deposited on gentle terrain by surface runoff is greatest below the longer and steeper slopes.

Generally, the steeper the gradient and the longer the slope, the greater the subsurface flow of soil water downslope. As a consequence, plants on lower slopes grow for longer periods without moisture stress than those on upper slopes. Subsurface flow may result in excessively wet soil with poor aeration at the base of long slopes. Lower slopes below the Plateau escarpment are an exception. Here, soil water percolates deep into the porous limestone instead of moving downslope in the soil.

Soil temperatures are lower on north-facing than on south-facing slopes. Because soils on north-facing slopes retain moisture longer during the growing season than those on south-facing slopes, both rate of tree growth and species composition are better on north-facing than on south-facing slopes. Gradient, aspect, slope length, and soil moisture are important in the delineation of landtypes described later.

Subregions

I have divided the Southern Cumberland Plateau into four subregions (fig. 2) that correspond fairly well to the forest habitat regions delineated by Hodgkins and others (1976). The subregions are: A—**Table Plateaus,** B—**Moderately Dissected Plateau,** C—**Strongly Dissected Plateau,** and D—**Shale Hills.** Subregions A, B, and C are reasonably similar, varying mostly in the degree of dissection. Soils are derived primarily from sandstone and in places from siltstone or shale or mixtures of the three. Subregion D is well dissected and soils are derived mostly from shale.

Subregion A — The **Table Plateaus** consist of Sand and Lookout Mountains. These two plateaus exhibit relatively little geologic dissection. Extensive areas of gently sloping soil are the dominant feature, and agriculture is common where soil depth exceeds 30 inches.

Subregion B — The **Moderately Dissected Plateau,** locally known as Brindley Mountain, occupies all of Cullman County, the southern part of Morgan County, and small parts of several other counties. Also included in Subregion B is Little Mountain, a narrow (2 to 8 miles) undulating low (600 to 800 feet high) plateau paralleling the Tennessee River and separated from the main Cumberland Plateau by the Moulton Valley. Subregion B has more geologic dissection than Subregion A, so there is a higher proportion of strongly sloping land and shallow soils. Soils on Little Mountain are simliar to those on Brindley Mountain, but parent rock (Harsells sandstone) is of Mississippian age, not Pennsylvanian as is the rest of the Cumberland Plateau. Agriculture is the dominant land use on the broad uplands and in the wider valleys.

Subregion C — The **Strongly Dissected Plateau** is the smallest of the four subregions and is so dissected that it no longer resembles a plateau. Topography is complex, and strongly sloping land predominates. The area is mostly forested and the Bankhead National Forest lies within this subregion.

Subregion D — The **Shale Hills** or Warrior Coal Basin comprise the southern extremity of the Cumberland Plateau. Dissection has largely removed the sandstone cap and exposed the underlying shale. Topography is rugged and fairly complex. Because ridgetops are much lower than those in more northerly sections of the Plateau, the character of the subregion is one of extensive hills, not mountains or a plateau. Strongly sloping land predominates, and the area is mostly forested although there is more farming than in Subregion C. Coal mining, both shaft and strip, is a major industry.

Landtypes

I have divided each subregion into landtypes, which are the smallest unit of the landscape recognized in this classification system. Wertz and Arnold (1975) describe landtypes as visually identifiable areas that have similar soils and productivity and have resulted from similar climatic and geological processes.

The Southern Cumberland Plateau Region has 21 recognizable landtypes (table 3) with landtypes 1-13 occurring in Subregions A, B, and C (figs. 3 and 4) and landtypes 14-21 occurring in Subregion D (fig. 5). Landtypes 1-6 occur exclusively on top of the Plateau. Landtypes 10-13 occur on the sides of the Plateau between the escarpment and the adjacent limestone valleys in Subregions A, B, and C and also between the escarpment and streambottoms in highly dissected Subregion C. Landtype 7 occurs almost anywhere on the landscape. Landtypes 8 and 9 occur in drainages both above and below the escarpment. Because no escarpment exists in Subregion D, all landtypes (14-21) occur only on top of the Plateau.

Aspect distinguishes some landtypes and is recorded as either north or south. North aspects include all azimuths from 315° (northwest) to 135° (southeast). The remainder of the azimuth circle represents south aspects.

Table 3.—*Summary of landtypes and their occurrence by subregions.*

	Landtype Number	
Landtype Location and Name	Subregions A, B, and C	Subregion D
Upland Landtypes on Top of the Plateau		
Narrow Ridges and Convex Upper Slopes	1	14
Broad Undulating Uplands	2	
Broad Ridges — North Aspect	3	15
Broad Ridges — South Aspect	4	16
North Slopes	5	17
South Slopes	6	18
Sandstone Glades, Rock Outcrops, and Plateau Edges	7	
Shale Rockland and Shallow Soils		19
Upland Landtypes on the Sides of the Plateau		
Sandstone Escarpment, Talus Slopes, and Benches — North Aspect	10	
Sandstone Escarpment, Talus Slopes, and Benches — South Aspect	11	
Lower Slopes, Benches, and Spur Ridges — North Aspect	12	
Lower Slopes, Benches, and Spur Ridges — South Aspect	13	
Sandstone Glades, Rock Outcrops, and Plateau Edges	7	
Landtypes Associated with Drainages		
Lower Slopes, Terraces, and Streambottoms with Good Drainage	8	20
Terraces and Streambottoms with Poor Drainage	9	21

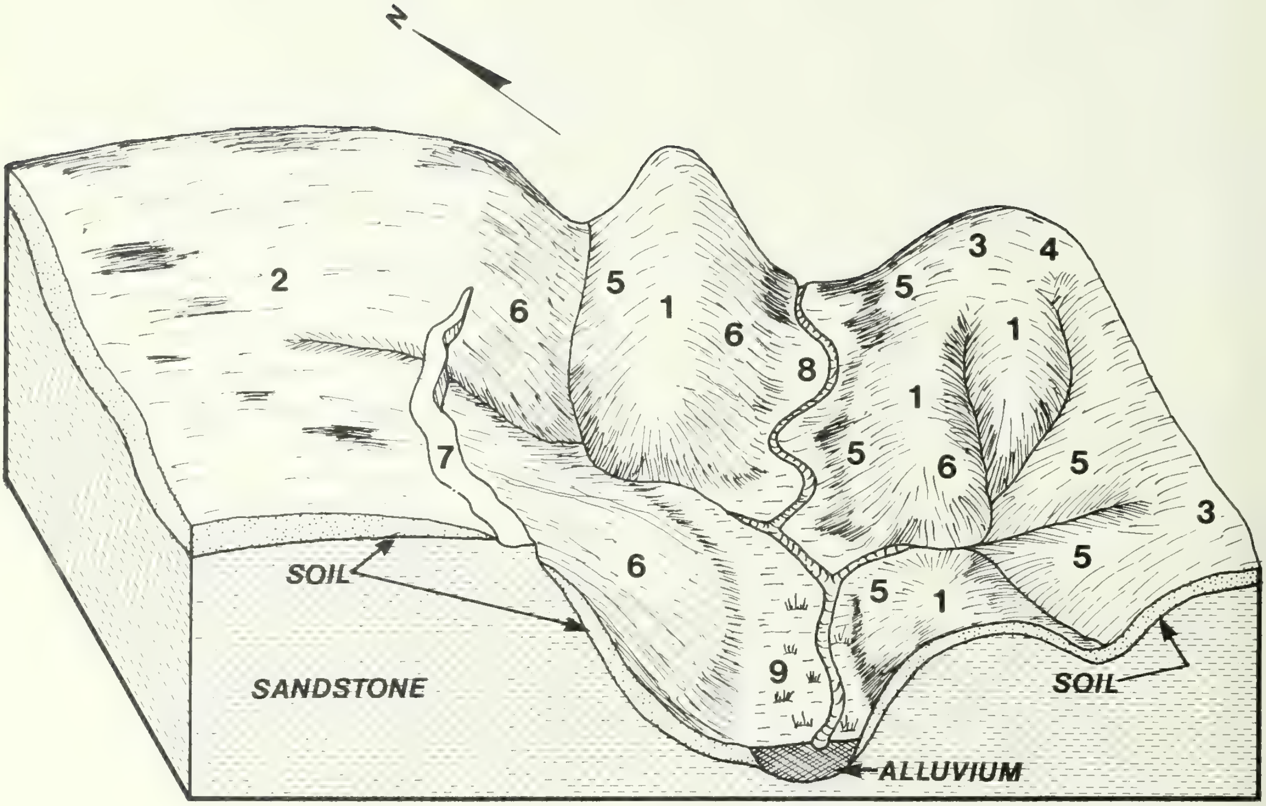

Figure 3. *Landforms on top of the Plateau and in drainages in Subregions A, B, and C where the caprock is mostly sandstone.*

FIGURE 3

Legend

1. Narrow ridges and convex upper slopes.
2. Broad undulating uplands.
3. Broad ridges, north aspect.
4. Broad ridges, south aspect.
5. North slopes.
6. South slopes.
7. Sandstone glades, rock outcrops, and plateau edges.
8. Lower slopes, terraces, and streambottoms with good drainage.
9. Terraces and streambottoms with poor drainage.

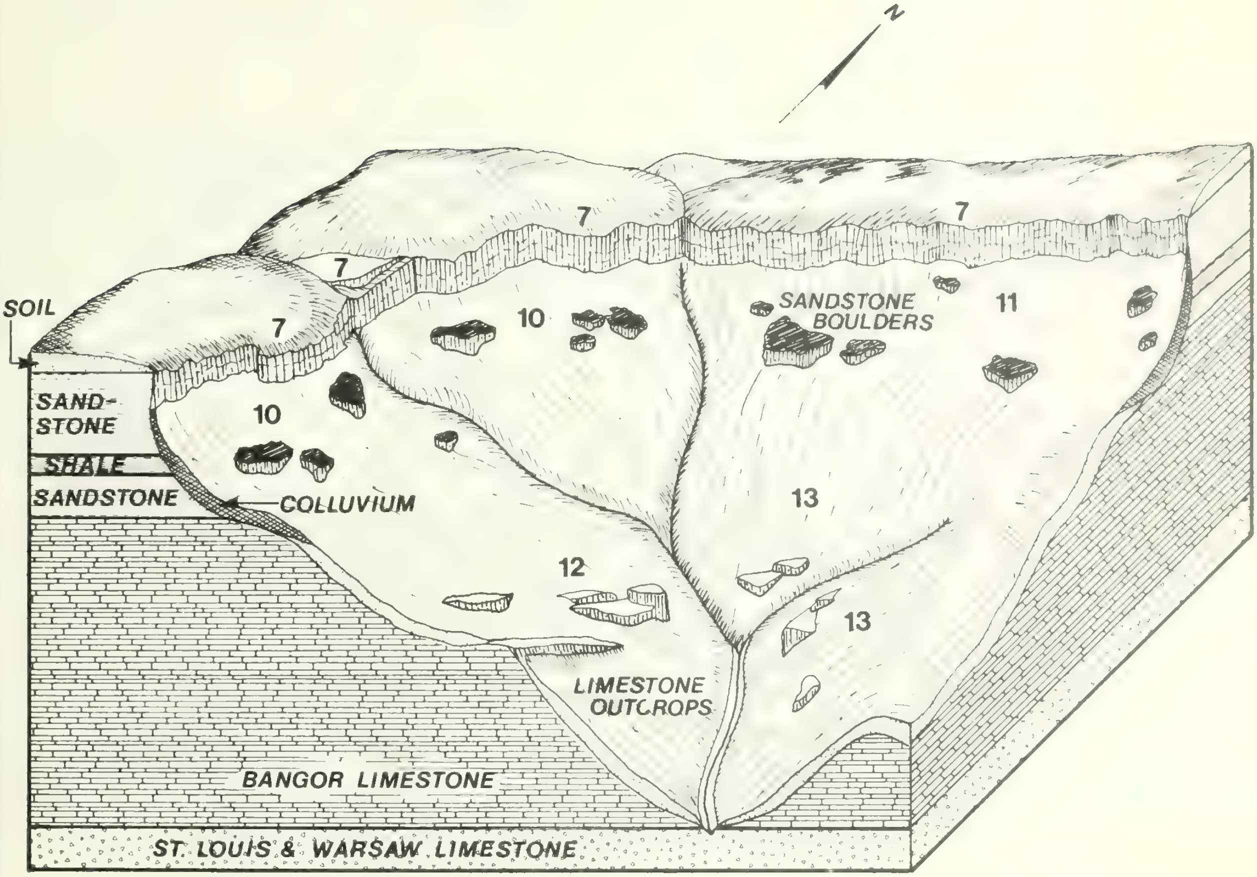

Figure 4. *Landforms on the sides of the Plateau in Subregions A, B, and C.*

FIGURE 4

Legend

7. Sandstone glades, rock outcrops, and plateau edges.
10. Sandstone escarpment, talus slopes, and benches; north aspect.
11. Sandstone escarpment, talus slopes, and benches; south aspect.
12. Lower slopes, benches, and spur ridges; north aspect.
13. Lower slopes, benches, and spur ridges; south aspect.

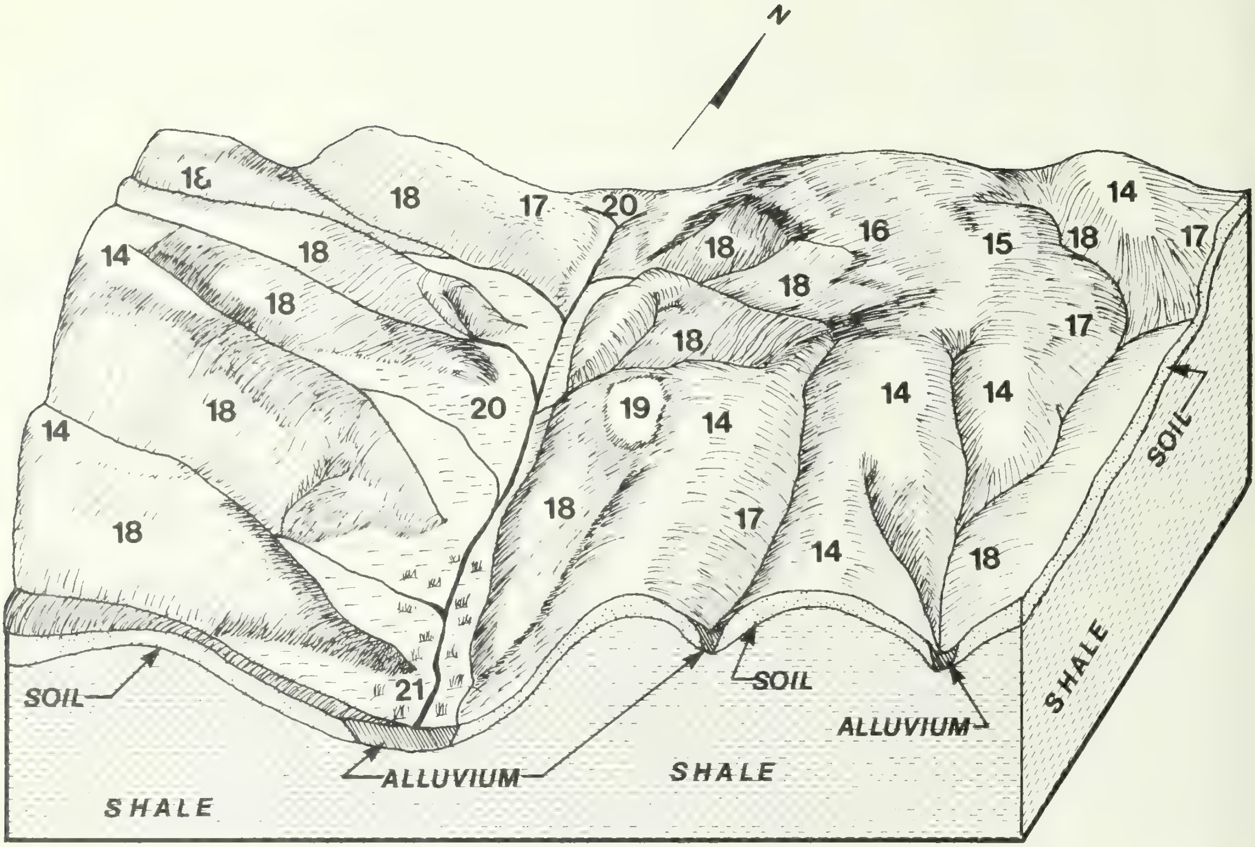

Figure 5. *Landforms on top of the Plateau and in drainages in Subregion D where the caprock is mostly shale.*

FIGURE 5

Legend

14. Narrow ridges and convex upper slopes.
15. Broad ridges, north aspect.
16. Broad ridges, south aspect.
17. North slopes.
18. South slopes.
19. Shale rockland and shallow soils.
20. Lower slopes, terraces, and streambottoms with good drainage.
21. Terraces and streambottoms with poor drainage.

Each landtype is described in terms of nine elements. The **Geographic Setting** provides an overall description of the landtype, specifying both where it occurs on the landscape and its relation to other landtypes. Slope was classified in accordance with SCS standards (Soil Survey Staff 1951).

Slope Classes and Corresponding Percent of Slope

Slope percent	Class
0- 2	Level or nearly level
2- 6	Gently sloping
6-10	Sloping
10-15	Strongly sloping
15-25	Moderately steep
25-45	Steep
45+	Very steep

The most prevalent soil series are listed under **Dominant Soils.** These series names reflect the most recent designations in soil classification and link this site classification system with county soil surveys published by the SCS. Users who wish more detailed information can refer to soil series descriptions issued by the SCS.

The kind of **Bedrock** or **Soil Parent Material** and **Depth to Bedrock,** are listed next. **Soil Texture** is described in terms of the 12 conventional classes, which are based on percentages of sand, silt, and clay-size particles (Soil Survey Staff 1951).

The conventional seven **Soil Drainage** classes are: *very poorly drained, poorly drained, somewhat poorly drained, moderately well drained, well drained, somewhat excessively drained,* and *excessively drained* (Soil Survey Staff 1951). **Relative Soil Water Supply** of each landtype is rated in five classes: *very low, low, medium, high,* and *very high.* This qualitative rating is based on the available water holding capacity of the dominant soils (a function of soil texture and thickness), but allowances are made for the influence of soil drainage, topographic position, and aspect.

Soil Fertility is described as: *very low, low, moderately low, moderate, moderately high, high,* or *very high.* Because soils of the Southern Cumberland Plateau are fairly acid and derived from rocks with few weatherable minerals, the most fertile soils in the region are rated only moderate (Francis and Loftus, 1977). The most common woody species in approximate order of abundance are listed under **Vegetation.** Some distinctive herbaceous species are included. Species nomenclature follows Little (1953) and Fernald (1950).

Forest Management Interpretations

Each landtype is evaluated in terms of productivity for selected species of trees and species desirability for timber production. Also, each landtype is rated for five soil-related problems that may affect forest management operations.

Productivity

Productivity of commercially valuable species is expressed as site index and as average annual growth in cubic feet per acre. Site index is the total height attained by dominant and codominant trees at some specified age.

For all naturally occurring species but upland oaks, site indices are the means of values from soil survey interpretations for dominant soils in each landtype. Interpretations are issued by the SCS as part of each soil series description. SCS personnel obtained height and age measurements in well-stocked, even-aged, essentially unmanaged stands that had not been damaged excessively by fire, insects, disease, or grazing. These stands were located on soils representing, as nearly as possible, the modal concept of each soil series. SCS personnel then used published site index curves (Beck 1962, Broadfoot 1960, Broadfoot and Krinard 1959, Nelson and others 1961, and U.S. Forest Service 1929) to convert height and age data to site indices. Curves for yellow-poplar, sweetgum, and the pines are based on age 50 years; those for cottonwood on age 30 years.

For upland oaks average site indices, base age 50 years, were derived from Smalley's (1967) soil-site study in Subregion C and Schnur's (1937) curves.

Site indices, base age 25 years, are given for loblolly and shortleaf pines in plantations established on abandoned fields (Smalley and Bower 1971) when data for specific landtypes were available.

In a few cases when no values were available, site indices, base age 50 years, of important species were estimated. Where they occur in tables 4 to 24 these estimated values are enclosed in parentheses.

Average annual growth expressed in cubic feet per acre was calculated from available yield tables (McCarthy 1933, Nelson and others 1961, Schnur 1937, U.S. Forest Service 1929, and Winters and Osborne 1935). The yield tables represent either normal or fully-stocked conditions. Annual growth rates for all naturally occurring species or forest types were averaged over 50 years.

Average annual growth rates for loblolly and shortleaf pine plantations were derived from Smalley and Bailey's (1974a, 1974b) variable-density yield tables, and a planting density of 1,000 seedlings per acre was assumed. Average growth was based on 40 years, the oldest age reported in the yield tables.

Though our productivity data are the best available, all site curves and yield tables except those for plantation-grown loblolly and shortleaf pine were developed either for geographic areas larger than but including the Southern Cumberland Plateau or for areas other than the Southern Cumberland Plateau.

Yields were not expressed in a common merchantability standard, so care should be exercised in comparing average annual yields of species both within and between landtypes. Footnotes to tables 4 to 24 specify merchantability standards used.

Management Problems

Plant Competition rates the invasion of unwanted plants after openings are made in the canopy. Plant competition is *slight* if unwanted plants do not prevent adequate natural regeneration, interfere with early growth, or restrict normal development of planted or seeded seedlings. Competition is *moderate* if unwanted plants delay establishment and hinder the growth of regenerated seedlings or if they retard the eventual development of a fully stocked stand. Competition is *severe* if unwanted plants prevent adequate restocking without extensive site preparaton or special maintenance practices. Competition ratings in tables 4 to 24 represent regional averages, and competition on a given landtype may vary as a result of past land use.

Seedling Mortality is the loss of artificially established tree seedlings as influenced by soils and topographic conditions, assuming that planting is done properly and plant competition is insignificant. Rating is *slight* if expected mortality is 0 to 25 percent, *moderate* if expected mortality is 26 to 50 percent, and *severe* if mortality is more than 50 percent. If the rating is moderate or severe, special preparation of the seedbed and special planting techniques are often necessary to insure a fully stocked stand.

Equipment Limitations are restrictions on use of conventional wheeled or tracked equipment. Soil and topographic characteristics such as slope, drainage, texture, and rockiness influence equpment limitations, sometimes necessitating the use of different kinds of equipment and methods of operation, or restricting the season when equipment is used. Generally, limitation is *slight* if slope is 20 percent or less and farm machinery can operate efficiently during all seasons. The rating is *moderate* if slope is 20 to 30 percent, limits the use of ordinary farm machinery, and requires track-type equipment; or if soil wetness prevents the use of logging vehicles for 2 to 6 months in a year. The rating is *severe* if slope exceeds 30 percent, making track-type equipment inadequate and requiring power vehicles and other special equipment; or if wetness prevents use of vehicles for 6 months or more in a year.

Erosion Hazard is the degree of potential soil erosion that can occur during and after forest management operations that expose soil along roads, skid trails, fire lanes, and landing areas. The ratings assume that the forest is well managed and is protected from fire and grazing. Soil and topographic characteristics considered in rating hazard of erosion include slope, infiltration, permeability, water holding capacity, and resistance to detachment of soil particles by rainfall and runoff. *Slight* indicates that no special measures are needed, *moderate* indicates that some attention needs to be given to erosion control, and *severe* indicates that intensive erosion-control measures are needed.

Windthrow Hazard measures how soils affect root development and how firmly soils hold trees. The hazard is *slight* if rooting depth is more than 20 inches and trees withstand most winds, *moderate* if effective rooting depth is 10 to 20 inches and some trees are blown down during excessive soil wetness and strong winds, and *severe* if effective rooting depth is 10 inches or less and trees will not stand alone in strong winds.

Three categories are used for rating **Species Desirability** of species that commonly occur on each landtype. *Most Desirable* species are those that have potential for fast growth, high value, or both. *Acceptable* species are those with moderate growth rate or value. *Least Desirable* species are those with slow growth, poor quality, or both. These ratings represent the average situation for the region. The presence or absence of local markets could result in a species being assigned to another category.

Using the System

This guide will allow professional foresters, forest landowners, landuse specialists, forest researchers, and other resource professionals to make on-site determination of site productivity and will provide a site-dependent framework for forest management planning and forest research.

To make on-site determinations of productivity on a particular tract of land the user must first identify specific landtypes by referring to the Landtype Descriptions. Then the user should refer to the table on the facing page to obtain information about productivity, severity of mangement problems, and species desirability.

This site classification system provides a sound biological basis for forest management planning because it recognizes inherent site differences and soil-related hazards. When the system is adopted landtypes become the basic unit of management. Continuous Forest Inventory or other forest inventory systems can easily be incorporated into this site classification system to obtain information on acreage, stocking, composition, and growth of forests by landtypes. Once productivity data are available for landtypes on a specific tract, they should be substituted for the regional values in the appropriate tables.

Users should be aware that productivity may vary considerably within a landtype. This variation should be handled as a sampling problem dependent on the desired precision of the productivity information. To adequately sample some landtypes, users with existing inventory systems may be required to install new plots or points. Excessive variation in productivity within a landtype may indicate the need to divide that landtype into more homogeneous units.

A logical vehicle to transfer this site classification system into a valuable forest management tool is a landtype map (fig. 6), which can be used in all phases of management from day-to-day activities to long-range planning. The number and scale of maps will depend on size of ownership and how intensively one wishes to manage. Landtypes can be mapped at scales

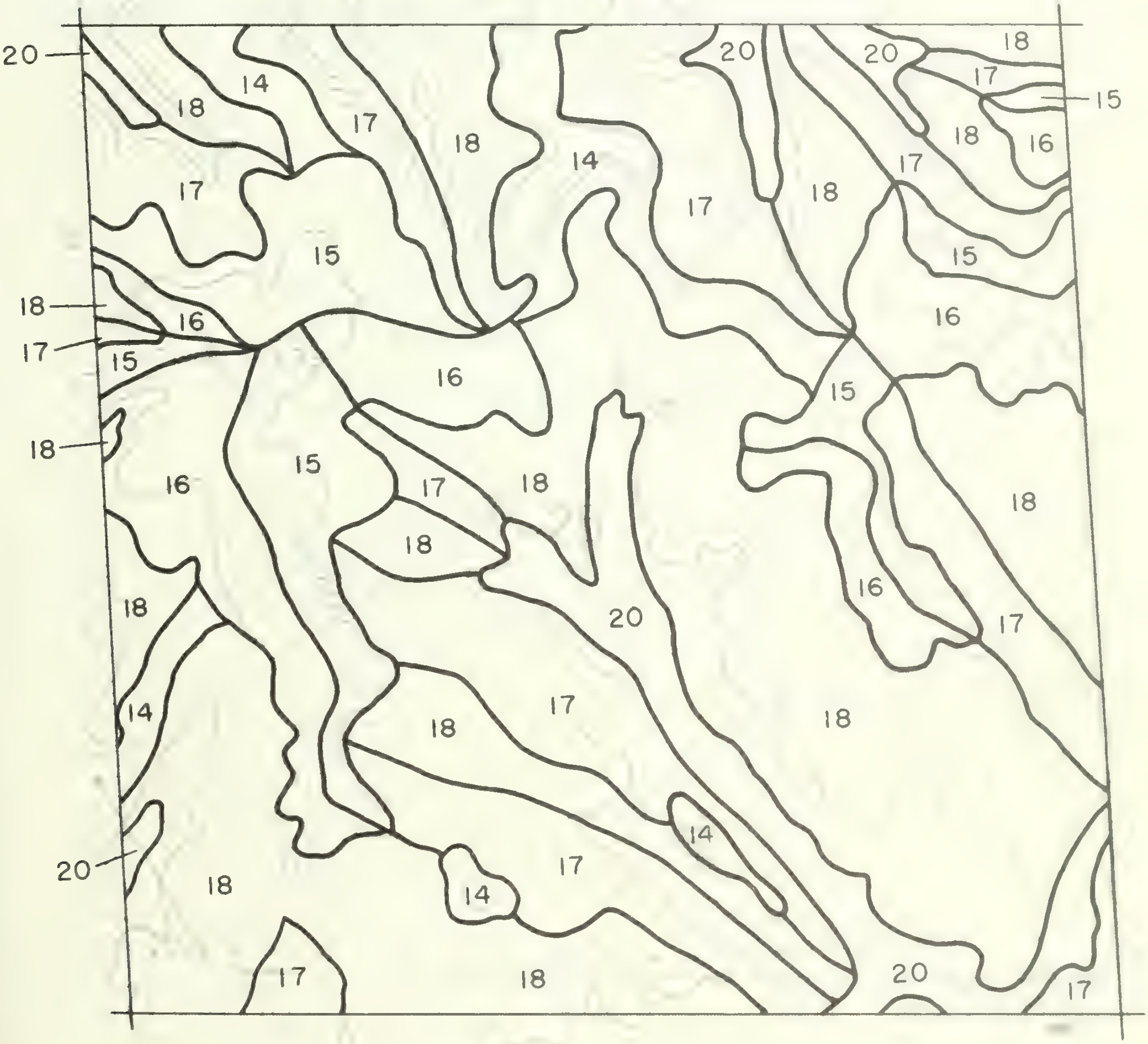

Figure 6. *A sample landtype map for Subregion D, the Shale Hills. Brookside Quadrangle, Jefferson County, Alabama. Section 25, T 15 S, R 4 W.*

of 1:10,000 to 1:40,000. So the U.S. Geological Survey 7½ minute quadrangle sheets (1:24,000) make excellent base maps on which to delineate landtypes. Black and white or color aerial photos of high contrast can also serve as base maps. A reasonable amount of ground checking should be part of the mapping process. Owners or managers of large tracts should explore the advantages of computer-generated mapping or landtypes and other physical and biological features of the landscape (Beeman 1978).

For forest researchers, this site classification system provides a basis for stratifying study areas. The system also aids in identifying and isolating problems that need to be researched. For example, it became apparent in compiling site index and growth information that little mensuration data specific to the region are available. Finally, the system provides researchers with a vehicle for quick transfer of research results to the practitioner. Study results can be reported on the basis of their applicability to specific landtypes.

DESCRIPTIONS AND FOREST MANAGEMENT INTERPRETATIONS FOR LANDTYPES IN SUBREGIONS

A. TABLE PLATEAUS

B. MODERATELY DISSECTED PLATEAU

C. STRONGLY DISSECTED PLATEAU

Description of Landtype 1:

NARROW RIDGES AND CONVEX UPPER SLOPES

Geographic setting — Shallow to moderately deep soils on gently sloping to steep, narrow, winding ridgetops and adjoining convex upper slopes. Slope ranges from 0 to 40 percent. Typically this landtype is no wider than 250 feet. Rock fragments, mostly sandstone, are common on the surface. Up to 50 percent of the soil mass may be coarse fragments. Along the western boundary of Little Mountain in Subregion B and in Subregion C in the transition to the Upper Coastal Plain, ridgetops may be capped with a few inches to several feet of unconsolidated Coastal Plain sediments. If these sediments are extensive, this site classification does not apply.

Dominant soils — Hartsells, Linker, Mountainburg, and Hector.

Bedrock — Predominantly sandstone and conglomerate with thin strata of shale or siltstone in places.

Depth to bedrock — 40 inches or less.

Texture — Fine sandy loam, sandy loam, loam; often channery, flaggy, or stony.

Soil drainage — Well-drained to somewhat excessively drained.

Relative soil water supply — Low to very low.

Soil fertility — Low.

Vegetation — White oak, southern red oak, scarlet oak, post oak, chestnut oak, black oak, shortleaf pine, Virginia pine, blackjack oak, hickories, and blackgum; occasional sweetgum and yellow-poplar. Dogwood, sassafras, sourwood, and huckleberries are common understory associates.

Table 4.—*Forest management interpretations for Landtype 1: Narrow Ridges and Convex Upper Slopes. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	70	55	104	133
Shortleaf pine	55	40	90	84
Virginia pine	60		53	
White oak	55		38-45	
Red oaks	60			
E. redcedar	35			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Slight to severe	Slight to severe	Slight to severe	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Post oak
Virginia pine	S. red oak	Blackgum
Shortleaf pine	Black oak	Hickories
	Chestnut oak	E. redcedar

Description of Landtype 2:

BROAD UNDULATING UPLANDS

Geographic setting — Moderately deep to deep soils on level to gently sloping uplands with slopes not exceeding 6 percent. Slopes are so gentle that aspect is not a factor. These uplands may be up to 0.5 mile in width. This landtype occurs frequently on Sand Mountain and occasionally on Lookout and Brindley Mountains but is rare in the more highly dissected portions of the Plateau. Rock fragments occur infrequently on the surface. Although as much as 50 percent of the soil mass may be coarse fragments, less rocky conditions predominate. Typically this landtype occupies the highest part of the landscape and grades into steeper broad ridges (Landtypes 3 and 4) or into mid-slopes (Landtypes 5 and 6). Depressions within these uplands should be classified as Landtype 9.

Dominant soils — Hartsells, Linker, Nectar, Wynnville, Albertville, and Enders.

Bedrock — Sandstone, conglomerate, shale, or siltstone; often interbedded.

Depth to bedrock — 20 inches to 6 feet.

Texture — Fine sandy loam, sandy loam, loam, and silt loam; occasionally channery, shaly, or stony.

Soil drainage — Well-drained except Wynnville soils which are moderately well drained.

Relative soil water supply — Medium.

Soil fertility — Moderately low.

Vegetation — White oak, southern red oak, scarlet oak, hickories, chestnut oak, black oak, yellow-poplar, blackgum, red maple, loblolly pine, and shortleaf pine. Dogwood, sassafras, and persimmon are common in the understory and abundant on abandoned fields and in stands that have been commercially clearcut. In some places huckleberries are abundant in the understory.

Table 5.—*Forest management interpretations for Landtype 2: Broad Undulating Uplands. Footnotes appear on page 58.*

PRODUCTIVITY

	Site index		*Average annual growth Cubic feet per acre*	
Species	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	75	55	114	133
Shortleaf pine	65	45	113	102
Virginia pine	70		92	
White oak	65		51	
Red oaks	65			
E. redcedar	40			
Yellow-poplar	75		63	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight	Slight	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Hickories
Yellow-poplar	S. red oak	Blackgum
Virginia pine	Black oak	Red maple
Shortleaf pine	N. red oak	E. redcedar

Description of Landtype 3:

BROAD RIDGES – NORTH ASPECT

Geographic setting — Moderately deep to deep soils on nearly level to steep north-facing portions of broad ridgetops and the adjoining convex upper slopes. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point there is usually an obvious increase in gradient. Slope ranges from 6 to 35 percent. Rock fragments occur on the surface in places. As much as 50 percent of the soil mass may be coarse fragments. These broad ridges may occur below the broad uplands (Landtype 2) in Subregions A and B. Along the western edge of the region, ridgetops may be capped with a few inches to several feet of unconsolidated Coastal Plain sediments. If these sediments are extensive, this site classification does not apply.

Dominant soils — Hartsells, Linker, Nectar, Wynnville, Albertville, and Enders.

Bedrock — Sandstone, conglomerate, shale, or siltstone; often interbedded.

Depth to bedrock — 20 inches to 6 feet.

Texture — Fine sandy loam, sandy loam, loam, and silt loam; occasionally channery, shaly, or stony.

Soil drainage — Well-drained except Wynnville soils, which are moderately well drained.

Relative soil water supply — Medium.

Soil fertility — Moderately low to low.

Vegetation — White oak, southern red oak, scarlet oak, hickories, black oak, yellow-poplar, blackgum, red maple, loblolly pine, and shortleaf pine. Dogwood, sassafras, and persimmon are common understory species that are abundant on abandoned fields and in stands that have been commercially clearcut. In some places, huckleberries are abundant in the understory.

Table 6.—*Forest management interpretations for Landtype 3: Broad Ridges – North Aspect. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	75	55	114	133
Shortleaf pine	65	45	113	102
Virginia pine	70		92	
White oak	65		51	
Red oaks	65			
E. redcedar	40			
Yellow-poplar	75		63	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight	Moderate to severe	Moderate to severe	Slight to severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Hickories
Yellow-poplar	S. red oak	Blackgum
Virginia pine	Black oak	Red maple
Shortleaf pine	N. red oak	E. redcedar

Description of Landtype 4:

BROAD RIDGES – SOUTH ASPECT

Geographic setting — Moderately deep to deep soils on nearly level to steep south-facing portions of broad ridgetops and the adjoining convex upper slopes. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point there is usually an obvious increase in gradient. Slope ranges from 6 to 35 percent. Rock fragments occur on the surface in places. The soil mass may have as much as 50 percent coarse fragments in some areas. South-facing ridges tend to be somewhat steeper and have shallower soils with a higher rock content than north-facing ridges. These broad ridges may occur below the broad uplands (Landtype 2) in Subregions A and B. Along the western edge of the region, ridgetops may be capped with a few inches to several feet of unconsolidated Coastal Plain sediments. If these sediments are extensive, this site classification does not apply.

Dominant soils — Hartsells, Linker, Nectar, Wynnville, Albertville, and Enders.

Bedrock — sandstone, conglomerate, shale, or siltstone; often interbedded.

Depth to bedrock — 20 inches to 5 feet.

Texture — Fine sandy loam, sandy loam, loam, silt loam; occasionally channery, shaly, or stony.

Soil drainage — Well-drained except Wynnville soils, which are moderately well drained.

Relative soil water supply — Medium to low.

Fertility — Moderately low to low.

Vegetation — White oak, southern red oak, scarlet oak, hickories, chestnut oak, Virginia pine, black oak, shortleaf pine, red maple, blackgum, and loblolly pine. Dogwood, sassafras, and persimmon are common in the understory and are abundant on abandoned fields and in stands that have been commercially clearcut. In some places, huckleberries are abundant in the understory.

Table 7.—*Forest management interpretations for Landtype 4: Broad Ridges – South Aspect. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	70	55	104	133
Shortleaf pine	55	40	90	84
Virginia pine	60		53	
White oak	60		45	
Red oaks	60			
E. redcedar	35			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight to moderate	Moderate to severe	Moderate to severe	Slight to moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Hickories
Virginia pine	S. red oak	Red maple
Shortleaf pine	Chestnut oak	Blackgum
	Black oak	E. redcedar
		Post oak

Description of Landtype 5:

NORTH SLOPES

Geographic setting — Shallow to moderately deep soils on north-facing linear or nearly linear mid-slopes. This landtype lies between the narrow winding ridgetops, broad uplands, or broad ridgetops and convex upper slopes (Landtypes 1, 2, and 3) and the lower concave slopes, terraces, and streambottoms (Landtypes 8 and 9). Slope ranges from 6 to 60 percent. Rock fragments are common on the surface. As much as 50 percent of the soil mass of sandy soils and 90 percent of shaly soils may be coarse fragments.

Dominant soils — Mountainburg, Hector, and Montevallo.

Bedrock — Sandstone or siltstone and sandy shale with lenses of sandstone.

Depth to bedrock — Less than 20 inches to sandstone; 20 to 40 inches to siltstone or shale.

Texture — Fine sandy loam, loam, and silt loam; usually channery, shaly, or stony.

Soil drainage — Well-drained.

Relative soil water supply — High to medium. Irrigated by subsurface flow.

Soil fertility — Moderately low to low.

Vegetation — White oak, northern red oak, black oak, chestnut oak, hickories, loblolly pine, southern red oak, scarlet oak, shortleaf pine, and Virginia pine; occasional American beech. Dogwood, persimmon, bigleaf magnolia, sourwood, and switch cane are common understory species.

Table 8.—*Forest management interpretations for Landtype 5: North Slopes. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	70	55	104	133
Shortleaf pine	55	40	90	84
Virginia pine	60		53	
White oak	75		63-69	
Red oaks	70			
Yellow-poplar	(80)		71	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Slight to moderate	Slight to moderate	Slight to moderate	moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Hickories
Virginia pine	N. red oak	American beech
Shortleaf pine	Black oak	
Yellow-poplar	S. red oak	
	Chestnut oak	

Description of Landtype 6:
SOUTH SLOPES

Geographic setting — Shallow to moderately deep soils on south-facing linear or nearly linear midslopes. This landtype occurs between narrow winding ridgetops, broad uplands, or broad ridgetops and convex upper slopes (Landtypes 1, 2, and 4) and lower concave slopes, terraces, and streambottoms (Landtypes 8 and 9). Slope ranges from 6 to 60 percent. Rock fragments are common on the surface. As much as 50 percent of the soil mass of sandy soils and 90 percent of shaly soils may be coarse fragments. South-facing slopes tend to be steeper and have shallower soils with higher rock contents than north-facing slopes.

Dominant soils — Mountainburg, Hector, and Montevallo.

Bedrock — Sandstone or siltstone and sandy shale with lenses of sandstone.

Depth to bedrock — Less than 20 inches to sandstone; 20 to 40 inches to siltstone or shale.

Texture — Fine sandy loam, loam, and silt loam; usually channery, shaly, or stony.

Soil drainage — Well-drained.

Relative soil water supply — Medium to low.

Soil fertility — Low to very low.

Vegetation — White oak, southern red oak, hickories, scarlet oak, chestnut oak, Virginia pine, post oak, black oak, shortleaf pine, red maple, blackgum, and black locust. Dogwood, sassafras, and huckleberries are common in the understory.

Table 9.—*Forest management interpretations for Landtype 6: South Slopes. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	60	45	86	98
Shortleaf pine	50	35	79	65
Virginia pine	50		<41	
White oak	65		45-51	
Red oaks	60			
E. redcedar	30			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Moderate	Moderate to severe	Moderate to severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Hickories
Virginia pine	S. red oak	Blackgum
Shortleaf pine	Chestnut oak	Black locust
	Black oak	Red maple
		E. redcedar
		Post oak

Description of Landtype 7:
SANDSTONE GLADES, ROCK OUTCROPS, AND PLATEAU EDGES

Geographic setting — Small to moderately large areas of shallow soils and bare rock on nearly level to moderately steep ridgetops, slopes, and edges of the Plateau above nearly vertical cliffs, and along deeply incised streams. Slope ranges from 0 to 45 percent. Outcropping sandstone occupies more surface in some areas than others. Slope of the rock surface usually is 5 percent or less. The very shallow dark brown or gray soils at the margins of these outcrops contain a very high percentage of organic matter. This landtype is associated with Landtypes 2, 3, 4, 5, 10, and 11 and sometimes with 1. Its extent varies from narrow strips to broad continuous areas. Landtype 7 has the lowest productivity of any Landtype in Subregions A, B, and C.

Dominant soils — Mountainburg, Hector, and Rockland-sandstone.

Bedrock — Predominantly sandstone and conglomerate with thin strata of shale or siltstone in places.

Depth to bedrock — Less than 20 inches.

Texture — Fine sandy loam, sandy loam, and loam; often gravelly, channery, or stony.

Soil drainage — Well-drained to somewhat excessively drained.

Relative soil water supply — Very low. Seepage is common in wet weather, but the soil dries quickly.

Soil fertility — Very low.

Vegetation — Virginia pine, white oak, post oak, blackjack oak, chestnut oak, shortleaf pine, hickories, scarlet oak, and black locust; occasional winged elm. Mountain laurel, huckleberries, lichens, and grasses are common understory species.

Table 10.—*Forest management interpretations for Landtype 7: Sandstone Glades, Rock Outcrops, and Plateau Edges. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index* Natural stands[1]	*Site index* Old-field plantations[2]	*Average annual growth Cubic feet per acre* Natural stands[3]	*Average annual growth Cubic feet per acre* Old-field plantations[4]
Shortleaf pine	50		79	
Virginia pine	50		41	
Upland oaks	(50)		32	
E. redcedar	(30)			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Severe	Moderate	Severe	Severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Virginia pine	White oak	Hickories
	Chestnut oak	Winged elm
	Shortleaf pine	Blackjack oak
	Post oak	
	E. redcedar	

Description of Landtype 8:

LOWER SLOPES, TERRACES, AND STREAMBOTTOMS WITH GOOD DRAINAGE

Geographic setting — Deep soils with good drainage on level to strongly sloping concave lower slopes, stream terraces, flood plains, and head of hollows on top of the Plateau. Slope ranges from 0 to 15 percent. This landtype typically occurs below Landtypes 5 and 6 as narrow stringers associated with the drainage network, but can also occur below Landtypes 1, 2, 3, or 4 particulaly near the heads of streams. When Landtypes 8 and 9 are adjacent, Landtype 8 occupies a higher position on the landscape. In gorges of the Plateau interior, primarily in Subregion C, this landtype occurs below Landtypes 10 and 11 where stream cutting has not carved through the sandstone caprock and below Landtypes 12 and 13 where stream cutting has carved through the sandstone caprock into the underlying Bangor limestone. This landtype is the second most productive one in the Region.

Dominant soils — Barbourville, Pope, Ealy, Philo, Clifty; occasionally Staser and Hamblen.

Parent material — Alluvium from sandstone, siltstone, and shale underlain by similar rocks on alluvium from sandstone, shale, and limestone underlain by limestone.

Depth to bedrock — 4 to 11 feet or more.

Texture — Fine sandy loam, loam, silt loam; occasionally gravelly.

Soil drainage — Well-drained to moderately well drained.

Relative soil water supply — High. Irrigated by subsurface flow.

Soil fertility — Moderate.

Vegetation — Red maple, yellow-poplar, white oak, blackgum, sweetgum, loblolly pine, northern red oak; occasional American sycamore, American beech, yellow buckeye, white ash, boxelder, eastern hemlock, white basswood, bigleaf magnolia, cucumbertree, and American elm. Sourwood, dogwood, and switch cane are common in the understory.

Table 11.—*Forest management interpretations for Landtype 8: Lower Slopes, Terraces, and Streambottoms with Good Drainage. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index* Natural stands[1]	*Site index* Old-field plantations[2]	*Average annual growth Cubic feet per acre* Natural stands[3]	*Average annual growth Cubic feet per acre* Old-field plantations[4]
Loblolly pine	85	65	134	162
Shortleaf pine	80	60	148	148
Virginia pine	75		120	
Yellow-poplar	100		107	
White oak	80		57-69	
Red oaks	70			
Sweetgum	90		81	
Cottonwood	(105)			
Bottomland oaks	(90)			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Moderate to severe	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Yellow-poplar	White oak	Red maple
Loblolly pine	Shortleaf pine	Blackgum
N. red oak	Virginia pine	E. hemlock
White ash	Black oak	Sourwood
White basswood	S. red oak	American beech
Sweetgum		
American sycamore		
Water oak		
Willow oak		
Cottonwood		

Description of Landtype 9:
TERRACES AND STREAMBOTTOMS WITH POOR DRAINAGE

Geographic setting — Deep soils with poor drainage on nearly level terraces, streambottoms, and upland depressions on top of the Plateau. Slope ranges from 0 to 3 percent. This landtype typically occurs below Landtypes 5 and 6 as narrow stringers and in depressions on broad undulating uplands, ridgetops, or in saddles in association with Landtypes 1, 2, 3, and 4. When Landtypes 8 and 9 are adjacent, Landtype 9 occupies a lower position on the landscape. In gorges of the Plateau interior, primarily in Subregion C, this landtype occurs below Landtypes 10 and 11 where stream cutting has not carved through the sandstone caprock and below Landtypes 12 and 13 where stream cutting has carved through the sandstone caprock into the underlying Bangor limestone.

Dominant soils — Johnsburg, Stendal, Atkins, Bonair, and Lickdale; occasionally Prader.

Parent material — Alluvium from sandstone, siltstone, and shale underlain by similar rocks or alluvium from sandstone, shale, and limestone underlain by limestone.

Depth to bedrock — 40 inches to 6 feet.

Texture — Predominantly silt loam, silty clay loam, and loam.

Soil drainage — Somewhat poorly to very poorly drained.

Relative soil water supply — Very high to high. Irrigated by subsurface flow.

Soil fertility — Moderate.

Vegetation — Red maple, sweetgum, willow oak, water oak, American sycamore, loblolly pine, and yellow-poplar; occasional boxelder, black willow, white ash, and American elm. Sphagnum moss and switch cane are common in the understory.

Table 12.—*Forest management interpretations for Landtype 9: Terraces and Streambottoms with Poor Drainage. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	85	65	134	162
Sweetgum	90		81	
Cottonwood	105			
Bottomland oaks	90			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Moderate	Severe	Slight	Moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Sweetgum	Loblolly pine	Red maple
Cottonwood	Yellow-poplar	Boxelder
Water oak	American sycamore	Black willow
Willow oak	White ash	
	American elm	

Description of Landtype 10:
SANDSTONE ESCARPMENTS, TALUS SLOPES, AND BENCHES – NORTH ASPECT

Geographic setting — Deep to very deep soils formed in colluvium or alluvium from sandstone, shale, and siltstone and underlain by sandstone or shale. Occupies the gently sloping to very steep upper one-third of northerly slopes that extend from the Plateau escarpment to the valley floor. Slope ranges from 2 to 70 percent. Much of the surface is covered with sandstone boulders and fragments. At the Plateau exterior this landtype may be absent if escarpment development has progressed down to limestone. In gorges of the Plateau interior, primarily in Subregion C, this landtype occurs where stream cutting has carved into the sandstone caprock and an escarpment is present. This landtype is a mesic site and has the highest productivity of any landtype in the Region.

Dominant soils — Grimsley and Jefferson. Formerly mapped as Sandstone rockland or Bouldery colluvial land.

Bedrock — Sandstone and shale.

Depth to bedrock — 40 inches to 5 feet or more.

Texture — Gravelly or cobbly loam, silty clay loam, or clay loam; occasionally sandy loam.

Soil drainage — Well-drained.

Relative soil water supply — Very high to high. Irrigated by subsurface flow and seepage.

Soil fertility — Moderate to moderately low.

Vegetation — Northern red oak, white oak, yellow-poplar, loblolly pine, American beech, white ash, white basswood, yellow buckeye, black oak, black cherry, sugar maple, black locust, redmaple, and cucumbertree. Bigleaf magnolia, dogwood, ironwood, and devil's club are common understory species.

Table 13.—*Forest management interpretations for Landtype 10: Sandstone Escarpment, Talus Slopes, and Benches – North Aspect. Footnotes appear on page 58.*

PRODUCTIVITY

Species	Site index Natural stands[1]	Site index Old-field plantations[2]	Average annual growth Cubic feet per acre Natural stands[3]	Average annual growth Cubic feet per acre Old-field plantations[4]
Loblolly pine	(80)		123	
White oaks	(75)		63-69	
Red oaks	(80)			
Yellow-poplar	(100)		107	
Black walnut	(90)			
Black cherry	(90)			
Shortleaf pine	65		113	
Virginia pine	(65)		70	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Severe	Moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Yellow-poplar	White oak	American beech
N. red oak	Black oak	Red maple
Loblolly pine	White basswood	Sugar maple
White ash	Cucumbertree	Black locust
Black walnut	Shortleaf pine	Bigleaf magnolia
Black cherry		Sourwood

Description of Landtype 11:

SANDSTONE ESCARPMENTS, TALUS SLOPES, AND BENCHES – SOUTH ASPECT

Geographic setting — Deep to very deep soils formed in colluvium or alluvium from sandstone, shale, and siltstone and underlain by sandstone or shale. Occupies the gently sloping to very steep upper one-third of southerly slopes, which extends from the Plateau escarpment to the valley floor. Slope ranges from 2 to 70 percent. Much of the surface is covered with sandstone boulders and fragments. At the Plateau exterior this landtype may be absent if escarpment development has progressed down to limestone. In gorges of the Plateau interior, primarily in Subregion C, this landtype occurs where stream cutting has carved into the sandstone caprock and an escarpment is present. This landtype is not as productive as Landtype 10, and forest stands lack the preponderance of mesic species found on north aspects.

Dominant soils — Grimsley and Jefferson. Formerly mapped as Sandstone rockland or Bouldery colluvial land.

Bedrock — Sandstone and shale.

Depth to bedrock — 40 inches to 5 feet or more.

Texture — Gravelly or cobbly loam, silty clay loam, or clay loam; occasionally sandy loam.

Soil drainage — Well-drained.

Relative soil water supply — Medium to low. Irrigated by subsurface flow and seepage. This landtype is not as moist as Landtype 10

Soil fertility — Moderately low to low.

Vegetation — White oak, chestnut oak, southern red oak, black oak, black locust, hickories, loblolly pine, shortleaf pine, and Virginia pine; occasional yellow-poplar, white ash, and black cherry. Dogwood and sourwood are common understory species.

Table 14.—*Forest management interpretations for Landtype 10: Sandstone Escarpment, Talus Slopes, and Benches – South Aspect. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Shortleaf pine	65		113	
Virginia pine	65		70	
Upland oaks	65		51	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Severe	Moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	Hickories	Sourwood
Shortleaf pine	Black locust	
Virginia pine		
White oak		
S. red oak		
Black oak		
Chestnut oak		
Yellow-poplar		

Description of Landtype 12:
LOWER SLOPES, BENCHES, AND SPUR RIDGES – NORTH ASPECT

Geographic setting — Shallow to very deep soils formed in colluvium or alluvium from sandstone and shale and underlain by either limestone or limestone residuum. Occupies the gently sloping to very steep lower two-thirds of northerly slopes that extend from the nearly vertical sandstone cliffs to the valley floor, or the entire northerly slopes of narrow spur ridges that extend into the adjacent valleys. Slope ranges from 2 to 75 percent. Sandstone boulders may be present, but up to 40 percent of the surface is covered with limestone outcrops and boulders. Soil material between the rocks is compact, sticky, heavy clay. Coarse fragments in the soil vary from less than 10 percent to 65 percent. This landtype usually occurs downslope from Landtype 10 and is less productive than north upper slopes. Where the escarpment has developed down to limestone, however, this landtype may extend from the base of the escarpment down to the adjoining valleys. This landtype does not occur in gorges of the Plateau interior where stream cutting has not carved through the sandstone caprock. Where stream cutting has carved through the sandstone caprock into the underlying Bangor limestone, this landtype occurs below Landtype 10 and above Landtypes 8 and 9.

Dominant soils — Bouldin, Allen, Nella. Formerly mapped as Limestone rockland or Bouldery colluvial land.

Bedrock — Limestone.

Depth to bedrock — A few inches to 10 feet or more.

Texture — Gravelly to stony loam, sandy clay loam, clay loam, and silt loam; occasionally sandy loam.

Soil drainage — Moderately well-drained to well-drained.

Relative soil water supply — Low. Soil water removed by deep percolation into the limestone.

Soil fertility — Moderately low.

Vegetation — Southern red oak, post oak, eastern redcedar, scarlet oak, chestnut oak, white oak, hickories, white ash, slippery elm, shortleaf pine, Virginia pine, and loblolly pine. Redbud, dogwood, winged elm, persimmon, and ironwood are common in the understory.

Table 15.—*Forest management interpretations for Landtype 12: Lower Slopes, Benches, and Spur Ridges – North Aspect. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Shortleaf pine	65		113	
Virginia pine	70		92	
Upland oaks	(60)		45	
E. redcedar	45			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Severe	Moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. redcedar	Hickories	Dogwood
White oak	Post oak	Persimmon
S. red oak	Scarlet oak	Redbud
White ash	Chestnut oak	Winged elm
Loblolly pine	Slippery elm	Ironwood
Shortleaf pine		E. redcedar
Virginia pine		

Description of Landtype 13:

LOWER SLOPES, BENCHES, AND SPUR RIDGES – SOUTH ASPECT

Geographic setting — Shallow to very deep soils formed in colluvium and alluvium from sandstone and shale and underlain by either limestone or limestone residuum. Occupies the gently sloping to very steep lower two-thirds of south slopes that extend from the nearly vertical sandstone cliffs to the valley floor, or the entire southerly slopes of narrow spur ridges that extend into the adjacent valleys. Slope ranges from 2 to 75 percent. Sandstone boulders may be present, but up to 40 percent of the surface is covered with limestone outcrops and boulders. Soil material between the rocks is compact, sticky, heavy clay. Coarse fragments in the soil vary from less than 10 percent to 65 percent. This landtype usually occurs downslope from Landtype 11. Where the escarpment has developed down to limestone, however, this landtype may extend from the base of the escarpment down to the adjoining valleys. This landtype does not occur in gorges of the Plateau interior where stream cutting has not carved through the sandstone caprock. Where stream cutting has carved through the sandstone caprock into the underlying Bangor limestone, this landtype occurs below Landtype 11 and above Landtypes 8 and 9.

Dominant soils — Bouldin, Allen, Nella. Formerly mapped as Limestone rockland or Bouldery colluvial land.

Bedrock — Limestone.

Depth to bedrock — A few inches to 10 feet or more.

Texture — Gravelly to stony loam, sandy clay loam, clay loam, and silt loam; occasionally sandy loam.

Soil drainage — Moderately well-drained to well-drained.

Relative soil water supply — Low to very low. Soil water removed by deep percolation into the limestone.

Soil fertility — Low to very low.

Vegetation — Southern red oak, post oak, eastern redcedar, chestnut oak, white oak, scarlet oak, hickories, white ash, slippery elm, Virginia pine, shortleaf pine, and loblolly pine. Redbud, dogwood, winged elm, persimmon, and ironwood are common in the understory.

Table 16.—*Forest management interpretations for Landtype 13: Lower Slopes, Benches, and Spur Ridges – South Aspect. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index* Natural stands[1]	*Site index* Old-field plantations[2]	*Average annual growth Cubic feet per acre* Natural stands[3]	*Average annual growth Cubic feet per acre* Old-field plantations[4]
Shortleaf pine	60		102	
Virginia pine	60		53	
Upland oaks	50		32	
E. redcedar	40			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate to severe	Severe	Moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. redcedar	Post oak	Dogwood
S. red oak	Chestnut oak	Persimmon
White oak	Scarlet oak	Redbud
White ash	Hickories	Winged elm
Shortleaf pine	Slippery elm	Ironwood
Virginia pine		
Loblolly pine		

DESCRIPTIONS AND FOREST MANAGEMENT INTERPRETATIONS FOR LANDTYPES IN SUBREGION

D. SHALE HILLS

Description of Landtype 14:

NARROW RIDGES AND CONVEX UPPER SLOPES

Geographic setting — Moderately deep soils on gently sloping to steep, narrow, winding ridgetops and adjoining convex upper slopes. Slope ranges from 2 to 45 percent. Shale fragments are common on the surface. Up to 90 percent of the soil mass may be coarse fragments.

Dominant soils — Enders, Townley, and Montevallo.

Bedrock — Shale and siltstone with a few thin strata of sandstone.

Depth to bedrock — 20 inches to about 3 feet.

Texture — Fine sandy loam, loam, and silt loam; often shaly.

Soil drainage — Moderately well-drained to well-drained.

Relative soil water supply — Medium to low.

Soil fertility — Moderately low to low.

Vegetation — Loblolly pine, Virginia pine, shortleaf pine, white oak, post oak, hickories, chestnut oak, longleaf pine, and blackgum. Dogwood, sourwood, and huckleberries are common in the understory.

Table 17.—*Forest management interpretations for Landtype 14: Narrow Ridges and Convex Upper Slopes. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	60	55	104	133
Shortleaf pine	60	45	102	102
Virginia pine	65		70	
Upland oaks	55		38	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight to moderate	Slight to moderate	Moderate	Slight to moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Hickories
Virginia pine	Post oak	Blackgum
Shortleaf pine	Chestnut oak	Dogwood
Longleaf pine	S. red oak	Sourwood

Description of Landtype 15:

BROAD RIDGES – NORTH ASPECT

Geographic setting — Moderately deep to deep soils on gently sloping to steep north-facing portions of broad ridgetops and the adjoining convex upper slopes. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point there is usually an obvious increase in gradient. Slope ranges from 0 to 35 percent. Shale fragments occur on the surface in places. As much as 50 percent of the soil mass may be coarse fragments. Along the western edge of Subregion D in the transition to the Upper Coastal Plain, ridgetops may be capped with a few inches to several feet of unconsolidated Coastal Plain sediments. If these sediments are extensive, this site classification does not apply.

Dominant soils — Enders, Albertville.

Bedrock — Shale, siltstone, with a few thin strata of sandstone.

Depth to bedrock — 20 inches to about 5 feet.

Texture — Fine sandy loam, loam, and silt loam; occasionally shaly.

Soil drainage — Well-drained.

Relative soil water supply — Medium.

Soil fertility — Moderate to moderately low.

Vegetation — Shortleaf pine, Virginia pine, loblolly pine, southern red oak, white oak, scarlet oak, hickories, blackgum, sweetgum, and red maple; occasional chestnut oak, blackjack oak, and longleaf pine particularly on the more sandy soils. Dogwood, huckleberries, hawthorn, and sourwood are common in the understory.

Table 18.—*Forest management interpretations for Landtype 15: Broad Ridges – North Aspect. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index* Natural stands[1]	*Site index* Old-field plantations[2]	*Average annual growth Cubic feet per acre* Natural stands[3]	*Average annual growth Cubic feet per acre* Old-field plantations[4]
Loblolly pine	80	60	123	148
Shortleaf pine	65	45	113	102
Virginia pine	70		92	
Upland oaks	65		51	
Yellow-poplar	(80)		71	
E. redcedar	40			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Slight	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Hickories
Yellow-poplar	N. red oak	Blackgum
Virginia pine	S. red oak	Red maple
Shortleaf pine	Scarlet oak	Blackjack oak
Longleaf pine	Chestnut oak	Sourwood
	Sweetgum	Dogwood

Description of Landtype 16:

BROAD RIDGES – SOUTH ASPECT

Geographic setting — Moderately deep to deep soils on gently sloping to steep south-facing portions of broad ridgetops and the adjoining convex upper slopes. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point there is usually an obvious increase in gradient. Slope ranges from 0 to 35 percent. Shale fragments occur on the surface in places. As much as 50 percent of the soil mass may be coarse fragments. South-facing ridges tend to be steeper and have shallower soils with higher rock contents than north-facing ridges. Along the western edge of the Region, ridgetops may be capped with a few inches to several feet of unconsolidated Coastal Plain sediments. If these sediments are extensive, this site classification does not apply.

Dominant soils — Enders, Albertville.

Bedrock — Shale, siltstone, with a few thin strata of sandstone.

Depth to bedrock — 20 inches to about 3 feet.

Texture — Fine sandy loam, loam, silt loam; occasionally shaly.

Soil drainage — Well-drained.

Relative soil water supply — Medium to low.

Soil fertility — Moderately low to low.

Vegetation — Shortleaf pine, Virginia pine, longleaf pine, southern red oak, scarlet oak, white oak, chestnut oak, post oak, blackjack oak, hickories, blackgum, and loblolly pine; occasional sweetgum and red maple. Huckleberries, hawthorn, and dogwood are common in the understory.

Table 19.—*Forest management interpretations for Landtype 16: Broad Ridges – South Aspect. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index* Natural stands[1]	*Site index* Old-field plantations[2]	*Average annual growth Cubic feet per acre* Natural stands[3]	*Average annual growth Cubic feet per acre* Old-field plantations[4]
Loblolly pine	70	55	104	133
Shortleaf pine	55	40	90	84
Virginia pine	60		53	
Upland oaks	55		38	
E. redcedar	35			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Moderate	Moderate	Moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Hickories
Longleaf pine	Chestnut oak	Blackgum
Virginia pine	S. red oak	Red maple
Shortleaf pine	Scarlet oak	Blackjack oak
	Sweetgum	Post oak
		Sourwood
		Dogwood

Description of Landtype 17:
NORTH SLOPES

Geographic setting — Shallow to moderately deep soils on north-facing linear to nearly linear mid-slopes. This landtype lies between the narrow winding or broad ridgetops and convex upper slopes (Landtypes 14 and 15) and the lower concave slopes, terraces, and streambottoms (Landtypes 20 and 21). Slope ranges from 6 to 45 percent. Shale fragments are common on the surface. Soils contain 10 to 90 percent shale fragments.

Dominant soils — Montevallo.

Bedrock — Predominantly shale.

Depth to bedrock — 20 to 40 inches.

Texture — Shaly loam, shaly silt loam.

Soil drainage — Well-drained.

Relative soil water supply — High to medium. Irrigated by subsurface flow.

Soil fertility — Moderately low to low.

Vegetation — Loblolly pine, shortleaf pine, Virginia pine, yellow-poplar, hickories, southern red oak, and white oak; occasional longleaf pine and blackgum. Dogwood, sourwood, switch cane, and huckleberries are common understory species.

Table 20.—*Forest management interpretations for Landtype 17: North Slopes. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	70	55	104	133
Shortleaf pine	60	45	102	102
Virginia pine	60		53	
Upland oaks	60		45	
Yellow-poplar	(90)		90	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Slight	Moderate	Moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	N. red oak	Hickories
Yellow-poplar	White oak	Sourwood
Virginia pine	S. red oak	Blackgum
Shortleaf pine	Longleaf pine	Dogwood

Description of Landtype 18:
SOUTH SLOPES

Geographic setting — Shallow to moderately deep soils on south-facing linear to nearly linear mid-slopes. This landtype occurs between narrow winding ridgetops or broad ridgetops and convex upper slopes (Landtypes 14 and 16) and concave lower slopes, terraces and streambottoms (Landtypes 20 and 21). Slope ranges from 6 to 45 percent. Shale fragments are common on the surface. Soils contain 10 to 90 percent shale fragments. South-facing slopes tend to be steeper and have shallower soils with higher rock contents than north-facing slopes.

Dominant soils — Montevallo.

Bedrock — Predominantly shale.

Depth to bedrock — 20 to 40 inches.

Texture — Shaly loam, shaly silt loam.

Soil drainage — Well-drained.

Relative soil water supply — Medium to low. Irrigated by subsurface flow.

Soil fertility — Low.

Vegetation — Virginia pine, shortleaf pine, hickories, southern red oak, white oak, loblolly pine, and longleaf pine. Dogwood and huckleberries are common in the understory.

Table 21.—*Forest management interpretations for Landtype 18: South Slopes. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index* Natural stands[1]	*Site index* Old-field plantations[2]	*Average annual growth Cubic feet per acre* Natural stands[3]	*Average annual growth Cubic feet per acre* Old-field plantations[4]
Loblolly pine	65	50	95	117
Shortleaf pine	55	40	90	84
Virginia pine	55		41	
Upland oaks	50		32	
E. redcedar	40			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Moderate	Severe	Moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	White oak	Hickories
Virginia pine	Chestnut oak	Post oak
Shortleaf pine	S. red oak	Dogwood
	Longleaf pine	
	Scarlet oak	

Description of Landtype 19:

SHALE ROCKLAND AND SHALLOW SOILS

Geographic setting — Small to moderately large areas of very shallow soils and bare rock on mostly steep and very steep slopes in association with Landtypes 14, 17, and 18. Also common along deeply incised streams. Slope ranges from 15 to over 45 percent. This landtype has the lowest productivity of any landtype in Subregion D.

Dominant soils — Rockland-shale and sandstone, Pottsville.

Bedrock — Predominantly shale with strata of siltstone and sandstone in places.

Depth to bedrock — Less than 10 inches.

Texture — Shaly silt loam, loam, and fine sandy loam.

Soil drainage — Well-drained to somewhat excessively drained.

Relative soil water supply — Very low. Seepage occurs in wet weather, but the soil dries quickly.

Soil fertility — Very low.

Vegetation — Virginia pine, southern red oak, chestnut oak, and hickories. Grasses, lichens, huckleberries, and winged elm are common in the understory.

Table 22.—*Forest management interpretations for Landtype 19: Shale Rockland and Shallow Soils. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations
Loblolly pine	60		86	
Shortleaf pine	50		79	
Virginia pine	50		<41	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Severe	Moderate	Severe	Severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Virginia pine	Chestnut oak	Hickories
Loblolly pine	S. red oak	Winged elm
Shortleaf pine	Scarlet oak	Post oak

Description of Landtype 20:
LOWER SLOPES, TERRACES, AND STREAMBOTTOMS WITH GOOD DRAINAGE

Geographic setting — Moderately deep to deep soils with good drainage on level to strongly sloping concave lower slopes, stream terraces, flood plains, and heads of hollows. Slope ranges from 0 to 6 percent. This landtype occurs below Landtype 17 and 18 as narrow stringers associated with the drainage network. When Landtypes 20 and 21 are adjacent, Landtype 20 occupies a higher position on the landscape. Landtype 20 is the most productive one in Subregion D.

Dominant soils — Leadvale, Sequatchie, Philo.

Parent material — Alluvium from shale, siltstone, and possibly sandstone underlain by shale.

Depth to bedrock — 3.5 feet or more. Leadvale soils have a fragipan at depths of 16 to 38 inches.

Texture — Mostly silt loam, but can range to sandy loam in Philo.

Soil drainage — Well-drained to moderately well-drained.

Relative soil water supply — High. Irrigated by subsurface flow.

Soil fertility — Moderate.

Vegetation — Yellow-poplar, sweetgum, loblolly pine, white oak, northern red oak, southern red oak, scarlet oak, shortleaf pine, and red maple; occasional American sycamore and cottonwood. Dogwood and switch cane are common in the understory.

Table 23.—*Forest management interpretations for Landtype 20: Lower Slopes, Terraces, and Streambottoms with Good Drainage. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	85	65	134	162
Shortleaf pine	75	55	136	134
Upland oaks	75		63	
Yellow-poplar	100		107	
Sweetgum	90		81	
Bottomland oaks	80			
American sycamore	(90)			
Cottonwood	(105)			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate to severe	Slight	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Yellow-poplar	White oak	Red maple
Loblolly pine	N. red oak	Dogwood
Sweetgum	S. red oak	
American sycamore	Shortleaf pine	
Cottonwood	Scarlet oak	

Description of Landtype 21:

TERRACES AND STREAMBOTTOMS WITH POOR DRAINAGE

Geographic setting — Moderately deep to deep soils with poor drainage on nearly level streambottoms, terraces, and upland depressions. Slope ranges from 0 to 3 percent. This landtype occurs below Landtypes 17 and 18 as narrow stringers and in depressions on broad ridgetops and in saddles in association with Landtypes 14, 15, and 16. When Landtypes 20 and 21 are adjacent, Landtype 21 occupies a lower position on the landscape.

Dominant soils — Tyler, Stendal, Atkins.

Parent material — Alluvium from shale, siltstone, or possibly sandstone underlain by shale.

Depth to bedrock — 4 feet or more.

Texture — Mostly silt loams.

Soil drainage — Somewhat poorly to poorly drained.

Relative soil water supply — Very high to high. Irrigated by subsurface flow.

Soil fertility — Moderate to moderately low.

Vegetation — Sweetgum, red maple, yellow-poplar, loblolly pine, white oak, American sycamore, willow oak, and water oak; occasional cottonwood.

Table 24.—*Forest management interpretations for Landtype 21: Terraces and Streambottoms with Poor Drainage. Footnotes appear on page 58.*

PRODUCTIVITY

Species	*Site index*		*Average annual growth Cubic feet per acre*	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	80	60	123	148
Sweetgum	90		81	
Bottomland oaks	80			
Cottonwood	105			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Moderate to severe	Slight	Moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Sweetgum	Yellow-poplar	Red maple
Cottonwood	White oak	
Loblolly pine	American sycamore	
Water oak		
Willow oak		

FOOTNOTES FOR TABLES 4-24

[1] Site indices for each naturally occurring species, except those for upland oaks and those enclosed in parentheses, are the means of values from soil survey interpretations issued by the SCS for the dominant soils in each landtype (Beck 1962, Broadfoot 1960, Broadfoot and Krinard 1959, Nelson and others 1961, and U.S. Forest Service 1929). Site indices for white oak and red oaks were derived from Smalley's (1967) soil-site study and Schnur's (1937) site index curves. Estimated site indices are enclosed in parentheses. Base age is 50 years for all naturally grown species except cottonwood, for which it is 30 years.

[2] Adapted from Smalley and Bower's (1971) site curves, base age 25 years.

[3] Annual growth of natural stands calculated from published yields at 50 years: Yellow-poplar — (McCarthy 1933, Table 17), inside-bark volume to a 3.0-inch i.b. top; trees >4.5″ d.b.h.; Sweetgum — Winters and Osborne 1935, Table 13), inside-bark volume to a 4.0-inch i.b. top, trees >4.5″ d.b.h.; Upland oaks — (Schnur 1937, Table 2, Column 12), outside-bark volume to a 4.0-inch o.b. top, trees>4.5″ d.b.h.; Virginia pine — (Nelson and others 1961, Table 4), outside-bark volume to a 4.0-inch o.b. top, trees >3.5″ d.b.h.; Loblolly and shortleaf pines — (U.S. Forest Service 1929, Tables 44 and 108), total volume outside bark, trees >3.5″ d.b.h.

[4] Annual growth of loblolly and shortleaf pine plantations calculated from yields at 40 years assuming 1,000 seedlings planted per acre (Smalley and Bailey 1974a, 1974b), outside-bark volume to a 4.0-inch o.b. top, trees >4.5″ d.b.h.

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APPENDIX

County Soil Surveys Available For The Southern Cumberland Plateau[1]

*Cotton, J. A., R. B. McNutt, G. L. Hickman, and K. E. Fussell.
1965. Soil survey of Fayette County, Alabama. USDA Soil Conserv. Serv. Series 1962, No. 4. 117 p. + maps.

Elder, J. A., E. K. Yates, and I. B. Epley.
1958. Soil survey of Marion County, Tennessee. USDA Soil Conserv. Serv. Series 1950, No. 2. 88 p. + maps.

Fussell, K. E., and E. A. Perry.
1959. Soil survey of Marshall County, Alabama. USDA Soil Conserv. Serv. Series 1956, No. 2. 61 p. + maps.

*McNutt, R. B., and E. A. Perry.
1962. Soil survey of Cullman County, Alabama. USDA Soil Conserv. Serv. Series 1959, No. 9. 73 p. + maps.

*Montgomery, C. F.
1978. Soil survey of Cherokee County, Alabama. USDA Soil Conserv. Serv. 78 p. + maps.

*Montgomery, C. F., H. G. Neal, and W. V. Anderson.
1978. Soil survey of Etowah County, Alabama. USDA Soil Conserv. Serv. 132 p. + maps.

Sherard, H., B. E. Young, H. J. Wesson, and M. J. Edwards.
1959. Soil survey of Lawrence County, Alabama. USDA Soil Conserv. Serv. Series 1949, No. 10. 83 p. + maps.

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1965. Soil survey of Franklin County, Alabama. USDA Soil Conserv. Serv. Series 1961, No. 19. 80 p. + maps.

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1958. Soil survey of DeKalb County, Alabama. USDA Soil Conserv. Serv. Series 1951, No. 3. 108 p. + maps.

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[1] Asterisk denotes survey that contains a section on woodland suitability.

Smalley, Glendon W.
1979. Classification and evaluation of forest sites on the Southern Cumberland Plateau. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-23, 59 p.

Presents a comprehensive forest site classification system for the southern portion of the Cumberland Plateau in northern Alabama, northwest Georgia, and extreme south-central Tennessee. The system is based on physiography, geology, soils, topography, and vegetation.

Additional keywords: Site index, mean annual increment, soil properties, pines, hardwoods.

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Energy Production from Hardwoods Growing on Southern Pine Sites

JOSEPH KARCHESY AND PETER KOCH

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Energy Production from Hardwoods Growing on Southern Pine Sites

JOSEPH KARCHESY AND PETER KOCH

Summary

Hardwoods on pine sites are a virtually untapped source of biomass for conversion to energy. This resource is substantial; above-ground stems 5 inches and larger in d.b.h. total about 49.2 billion ft^3 amounting to about 888 million tons of wood and bark, ovendry. Complete-tree biomass, including branches and central root systems of these trees, and those too small to be surveyed, probably totals at least 100 billion ft^3, or 1,805 million tons, ovendry.

Direct combustion is the most promising process for converting such biomass to energy—principally in the form of heat for process steam. A wide array of burners is available, ranging from highly efficient domestic stoves to industrial systems such as fuel cell burners, inclined-grate furnaces, spreader stokers, suspension-fired burners, cyclonic furnaces, and fluidized-bed burners. Average heat of combustion (higher heating value) for ovendry stemwood of pine-site hardwoods is about 7,827 Btu per pound; bark and branchwood have slightly less heat content. Moisture content of pine-site hardwood stemwood averages about 73.5 percent of dry weight; that of bark averages 67.6 percent. As a replacement for natural gas (at $2 per million Btu) to generate steam, pine-site hardwoods have a fuel value of about $15 per green ton, and when used to replace oil the value is slightly higher.

Fuel costs, however, are only one consideration in the total economic picture. Wood-fired boilers cost more and are more expensive to maintain than oil- or gas-fired units. The key to economic success in use of wood for heat energy is development of harvesting systems that deliver wood to the plant fuel pile at low cost.

Gasification of wood is a versatile process that can lead to a number of energy-related products. After direct combustion, gasification with on-site combustion of the low Btu producer gas appears to be the best alternative for conversion of the pine-site hardwoods to heat energy. With the development of fuel cells, producer gas may be used in the future to generate electricity. Synthesis gas (the hydrogen and carbon monoxide components of producer gas) can be converted to many important fuels and chemicals, but none seem economically competitive when produced by this route until at least the end of the century, barring unforeseen disruptions in the world distribution system for oil.

Charcoal manufacture is a well established industry. Opportunities may exist for further development of plants that effectively use the off-gases.

Liquefaction processes yielding a wood oil are possible, but appear not economically competitive. Hydrolysis of wood and subsequent conversion of sugars and lignin to yield ethanol, furfural, and phenol, or to produce a yeast for protein supplement have yet to be proven economically competitive. Prehydrolysis products from waste streams of primary wood products plants have achieved some economic success.

In summation, wood fuel will be increasingly used by the forest products industry, however the industry will probably depend partially on gas and oil for

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The authors are Joseph Karchesy, a visiting scientist at the Pineville Laboratory of the Southern Forest Experiment Station, on leave of absence from the University of Oregon, and Peter Koch, Chief Wood Scientist, Forest Products Utilization Research, Southern Forest Experiment Station, Forest Service—USDA, Pineville, Louisiana.

as long as they are available; coal will supply perhaps one-fourth of the industry's fuel needs by the end of the century. Oil and gas will continue to be the primary feed stocks for organic chemicals through the turn of the century. For better chemical utilization of wood, research should focus on making the ligno-cellulosic complex accessible to chemical and biological action, increased use of cellulose and lignin as polymers, producing specialized chemicals, and catalyst research and development. Economic feasibility of all processes to convert forest residues into energy depends largely on the cost of wood; development of appropriate harvesting equipment is, therefore, the number one research priority.

CHAPTER 1

Introduction

The United States uses about one-third of the total energy produced in the world. Since the 1973 oil embargo, we have become aware that our energy sources are not inexhaustible; and, they are no longer cheap. We are compelled, therefore, to assess our energy needs for the future and to seek new sources.

The amounts of energy consumed today are very large and are therefore measured in millions of barrels per day oil equivalent or in quads. A barrel of oil has a heat content of 5.55 million British thermal units (Btu) (Exxon Company 1978). One quad is equal to 10^{15} Btu's or about 494,000 barrels of oil per day for a year, as follows:

$$1 \text{ quad} = \frac{10^{15} \text{ Btu}}{5.55 \times 10^{6} \text{ Btu/barrel} \times 365 \text{ days}}$$
$$= 493{,}644 \text{ barrels/day}$$

The Department of Energy (1978) has projected that by 1990 the total consumption of energy by the United States could range from 100.7 to 109.4 quads per year.

In another projection of demand (Exxon Company 1978), the United States is forecast to increase its energy consumption from 38 million barrels per day oil equivalent (just under 77 quads annually) in 1977 to 51 million barrels per day oil equivalent (103 quads annually) by 1990. The assumptions made in this projection include the following: the growth rate of the gross national product will be just under 3.6 percent annually; environmental goals will be achieved at a rate comparable with economic growth; and oil imports will be available at a price that will increase at about the same rate of inflation.

Oil will remain the predominant fuel through 1990 (fig. 1-1). However, oil imports will have to increase from about 45 percent of the total oil supply in 1977 to about 57 percent of the supply in 1983 and then will decline slightly through 1990. Gas will have limited availability and will decline to about 17 percent of our energy base by 1990. Nuclear energy (which is limited to electric utility use) will increase to 10 percent of our energy base. Hydroelectric and geothermal energy have small growth potentials due to the limited number of sites where such energy is available.

Coal reserves in the United States are substantial. The Department of Energy estimates that the proven domestic reserve amounts to about 4,000 quads (fig. 1-2). However, logistical and technological gaps prevent us from fully using this potential now. Extensive research and development are underway to find methods for converting coal into fuels that are economically acceptable and environmentally clean. Coal usage is expected to grow from 18 percent of our energy base in 1977 to 27 percent in 1990.

Among potential sources, one that has generated considerable interest—mainly because it is renewable—is *biomass,* that is, living matter. For example, the U.S. Department of Energy is assessing the technical and economic feasibility of using intensively managed, short-rotation tree farms as a source of energy for the future.

Essentially, biomass is a form of stored solar energy. That is, green plants use sunlight as energy in *photosynthesis* to convert carbon dioxide (CO_2) and water (H_2O) to higher energy products, that is carbohydrates $(CH_2O)_n$ and oxygen (O_2). While carbohydrates are the principal organic products of photosynthesis, plants can produce other compounds such as hydrocarbons, fats, and proteins in the process (Calvin 1976, Bassham in press). Overall photosynthetic conversion efficiency for plants in the temperate zone ranges from 0.1 to 1 percent of the total available sunlight. Calvin (1976) envisions that eventually a synthetic system will be developed to simulate plant photosynthesis to produce renewable fuel.

Estimates of the annual storage of solar energy in the U.S. biomass system are as high as 80 quads a year (Falkehag 1977). The U.S. Department of Energy estimates 7 to 8 quads are produced annually in our forests (Del Gobbo 1978). Standing available forests contribute about 300 quads to the proven reserves of energy in the U.S. (fig. 1-2).

The equivalent of about 4 quads of our forests are harvested annually for lumber and paper products. These products are more valuable than fuel. However, the residues from these resources can be, and perhaps should be, utilized for energy.

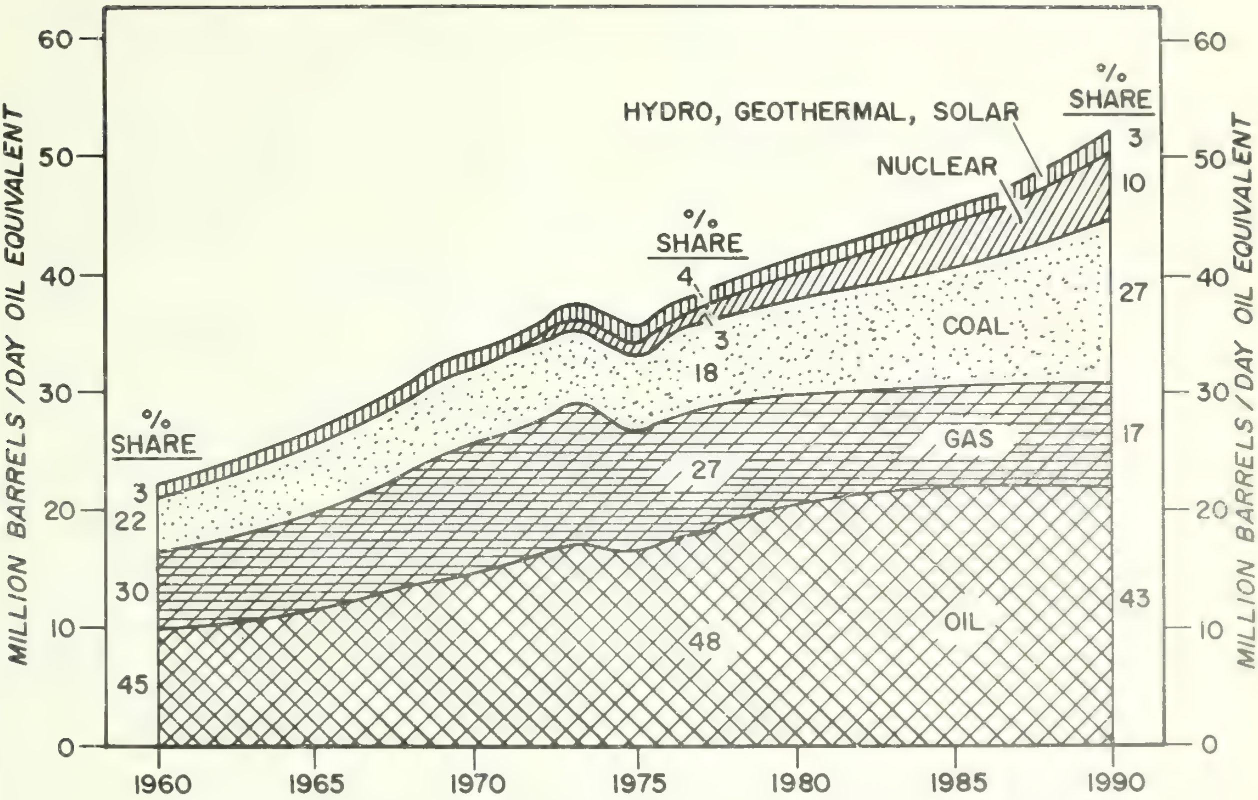

Figure 1-1.—*U.S. energy supply projected to 1990. Top line represents 100 percent of the energy supply which is broken down into contributing percentages from oil, gas, coal, and nuclear energy, and the group hydro, geothermal and solar energy (Drawing after Exxon Company, 1978.)*

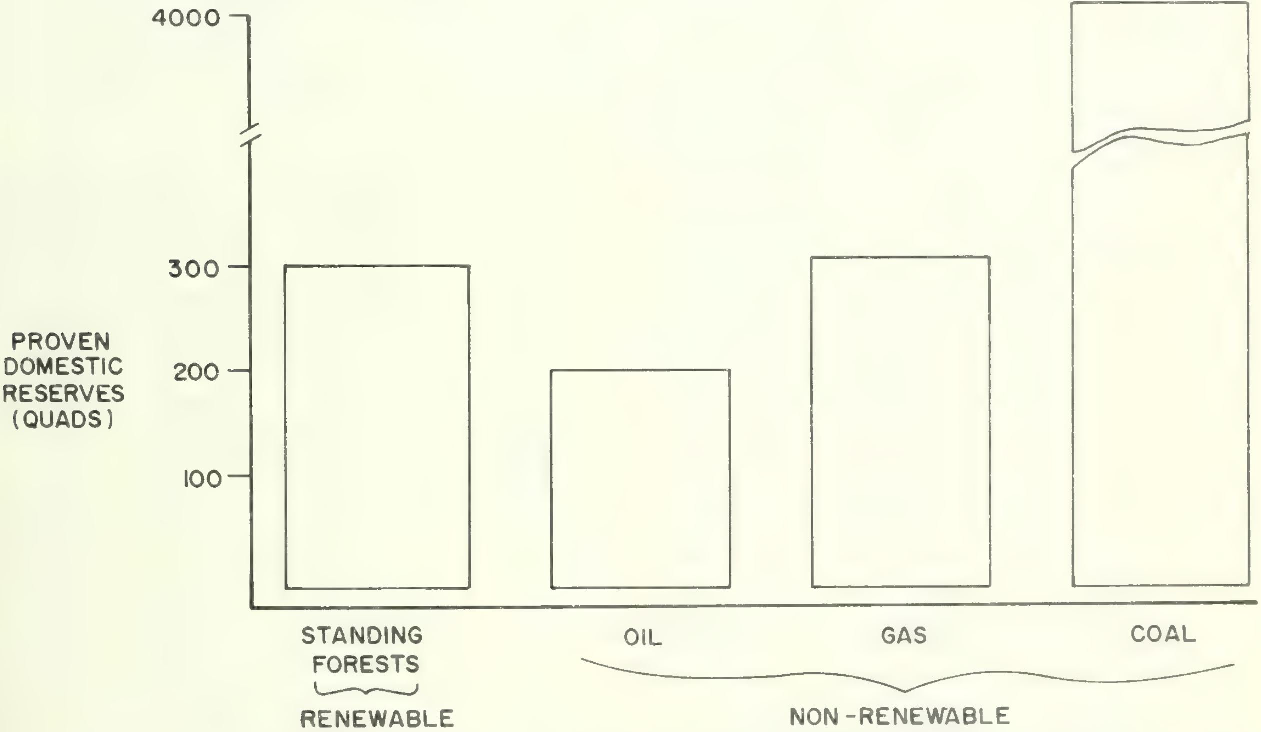

Figure 1-2.—*Proven reserves of energy in the U.S. Renewable reserves are considered to be 730 million acres of standing forests with an annual production of 7 to 8 quads. Oil, gas, and coal are the non-renewable resources. Coal is the largest reserve with about 4,000 quads of energy. (Drawing from Department of Energy.)*

The forest products industry already produces about 1 quad of energy from its residues. In the near term, an additional 0.5 to 1.0 quad could be realized from combined forestry and agricultural residues. The projected contribution of biomass to our national energy requirements by the year 2000 ranges from 3 to 8 quads (Del Gobbo 1978, Zerbe 1977). To aid in achieving this goal, the Department of Energy has established a Fuels from Biomass Program. Its objective is to develop technologies for the preparation, harvest, and conversion of renewable biomass into clean fuels, petrochemical substitutes, and other energy-intensive products (Del Gobbo 1978).

In the South, hardwoods growing on pine sites are a virtually unused source of biomass. Over the years attempts to use these hardwoods have been thwarted by the diversity of species, scattered occurrence, smallness and shortness of boles, branchiness of crowns, and prevalence of knots. Therefore, most of these hardwoods are destroyed during site preparation for pine—a destruction that is wasteful and costly (perhaps $85 per acre). Economic uses for these hardwoods would be desirable and at least two utilization schemes have been proposed (Goldstein et al. 1978, Koch 1978). In the energy self-sufficient Koch approach, a new harvesting and utilization system known as BRUSH (Biomass Recovery and Utilization with Shaping-Lathe Headrigs) could recover 67 percent of the tree biomass of all species as solid wood products. In the Goldstein et al. approach, entire hardwood trees are chipped in the woods. Such chips can be used for fuel, production of chemicals, or fiberboard.

In the chapters that follow, we will review the potential of using the pine-site hardwoods, or their residues from manufacturing processes, as a source for energy, fuels and chemicals. Conversion processes that are available or near at hand will be described, and potential uses and economics of the conversion products will be discussed.

CHAPTER 2

The Raw Material

2-1 The Resource

The total hardwood resource of the South recently was estimated at 113.7 billion ft^3 which amounts to 2,051 million tons of ovendry wood and bark. This resource, which is spread over 12 states, can be divided into that on southern pine sites and that on hardwood sites. Pine sites are defined as forested uplands, excluding those growing cove-type hardwoods, that support southern pine or show evidence, like stumps, of its former occurrence. Hardwoods on pine sites total about 49.2 billion ft^3 of wood (888 million tons of wood and bark, ovendry) or 43 percent of the total hardwood inventory (table 2-1).

How have pine sites become so heavily invaded by hardwoods? In most of the South, plant succession—the replacement of one plant community by another—climaxes with a hardwood forest (Billings 1938, Quarterman and Keever 1962). Establishment of pine stands requires the absence of heavy litter and freedom from competing plant cover; wildfires often provide these conditions and check the succession to hardwoods. However, man has largely excluded fire from the forest, thus favoring the shade-tolerant hardwoods.

About 90 percent of the total hardwood volume on southern pine sites is composed of 23 species or species groups representing 10 genera (table 2-2). The inventoried hardwoods (table 2-3) are only about one-half of the total hardwood biomass (excluding foliage) grown on these sites; the other half is in roots, stumps, and branches of inventoried stems and in trees smaller than 5 inches d.b.h.

Oaks comprise 47 percent of the 12-state volume of hardwoods on pine sites. Sweetgum and white oak are the leading species, each with an inventory of more than 6 billion ft^3. The hickories, third in abundance, are widespread, though on pine sites their quality tends to be poor. The five most abundant pine site hardwoods, sweetgum, white oak, hickory,

Table 2-1.—*Volume of all hardwoods on pine sites and hardwood sites in 12 Southern States (Christopher et al. 1976)*[1]

	All sites	Pine sites	Hardwood sites
		Million cubic feet	
Alabama	10,886	6,456	4,430
Arkansas	11,174	4,926	6,248
Florida	5,461	1,078	4,383
Georgia	12,999	6,600	6,399
Louisiana	9,879	3,085	6,794
Mississippi	8,416	3,827	4,589
North Carolina	17,074	6,838	10,236
Oklahoma	1,601	633	968
South Carolina	8,093	3,358	4,735
Tennessee	10,255	3,724	6,531
Texas	4,222	2,593	1,629
Virginia	13,651	6,118	7,533
	113,711	49,236	64,475

[1] From source data gathered during 1964-1974 on systematic sample plots 2 to 4 miles apart. The volume is expressed in cubic feet inside bark of trees from stump to a minimum 4-inch top diameter (outside bark) of stem. All trees 5 inches in diameter at breast height are included.

Table 2-2.—*The major hardwood species on pine sites*

Common name	Botanical name
Ash, green	*Fraxinus pennsylvanica* Marsh.
Ash, white	*F. ameriana* L.
Elm, American	*Ulmus americana* L.
Elm, winged	*U. alata* Michx.
Hackberry	*Celtis* spp.
Hickory	*Carya* spp.
Maple, red	*Acer rubrum* L.
Oak, black	*Quercus velutina* Lam.
Oak, blackjack	*Q. marilandica* Muenchh.
Oak, cherrybark	*Q. falcata* Michx. var. *pagodaefolia* Ell.
Oak, chestnut	*Q. prinus* L.
Oak, laurel	*Q. laurifolia* Michx.
Oak, northern red	*Q. rubra* L.
Oak, post	*Q. stellata* Wangenh.
Oak, scarlet	*Q. coccinea* Muenchh.
Oak Shumard	*Q. shumardii* Buckl.
Oak southern red	*Q. falcata* Michx.
Oak, water	*Q. nigra* L.
Oak, white	*Q. alba* L.
Sweetbay	*Magnolia virginiana* L.
Sweetgum	*Liquidambar styraciflua* L.
Tupelo, black	*Nyssa sylvatica* Marsh.
Yellow-poplar	*Liriodendron tulipifera* L.

Table 2-3.—*Species volumes on pine sites in the 12 southern states*

Species	Volume	Proportion of pine site hardwood volume
	Million cubic feet	*Percent*
Sweetgum	6,508	13.2
Oak, white	6,058	12.3
Hickory, spp.	4,173	8.5
Oak, southern red	3,994	8.1
Oak, post	3,444	7.0
Yellow-poplar	3,421	7.0
Tupelo, black	2,710	5.5
Oak, water	2,332	4.7
Oak, chestnut	2,102	4.2
Oak, black	1,949	4.0
Oak, scarlet	1,799	3.6
Maple, red	1,751	3.6
Oak, northern red	1,169	2.4
Oak, laurel	683	1.4
Elm, spp.	668	1.4
Oak, cherrybark	579	1.2
Ash, spp.	441	.9
Sweetbay	300	.6
Oak, Shumard	120	.2
Hackberry, spp.	57	.1
Other hardwoods	4,978	10.1
Total hardwoods	49,236	100.0

[1] Compiled from data of Christopher et al. (1976).

southern red oak, and post oak, and the seventh, black tupelo, are well represented in all 12 States. Yellow-poplar, scarlet oak, and chestnut oak are scarce or absent west of the Mississippi and in Florida. Black oak is plentiful except in Florida, T[illegible] Louisiana, and Oklahoma. Among other species making up 2 percent or more of the hardwood on pine sites, red maple is well distributed except in Oklahoma, water oak is scarce only in Tennessee and Oklahoma, and northern red oak is scarce in the Gulf States.

Many factors make using these hardwoods difficult. Trees are often scarred and defective from fires and from previous pine harvesting. They are slow growers because the sites are not right for them —trees 6 inches in diameter at breast height are typically 40 years of age (Manwiller 1974). They are short and crooked in bole. The low cubic content per stem, the highly variable species mix from stand to stand and even from site to site within stands, and the low volume per acre all combine to raise harvesting costs. Moreover, the value of the trees after harvest is low. Knots and other defects, short lengths, and small diameters preclude any hope of sawing quality lumber in conventional lengths. Not least among the problems is that of maintaining a species mix suitable for a manufacturing operation (Barber 1975).

Offsetting these disadvantages are some advantages. The resource is distributed throughout the southern pinery and therefore is available near many potential consumers. Because the volumes are substantial, they can supply a market of almost any realizable size—and at a variety of locations. A supply will always exist because on many sites hardwoods replace southern pines in natural succession, and certain sites, such as areas bordering intermittent streams in uplands, will remain in hardwoods for environmental reasons. Stumpage cost is low, thus leaving much of the final product value for harvest and manufacture. New industries based on these hardwoods can be located in depressed rural areas where labor is readily available, and local communities are frequently eager to help in plant establishment. Finally, factories utilizing these hardwoods can be energy self-sufficient (Barber 1975).

Improved utilization of hardwoods from all sites should hasten the time when wood production can be maximized by concentrating hardwood management on sites best suited for hardwoods and pine production on lands best suited for pines. Hardwood sites intermingled with pine lands will permit a desirable pattern of diversity in most areas. Moreover, substantial acreages suitable for high production of either hardwoods or pine are available; these lands can be allocated to either species group as needed to balance demands, not only for industrial wood products, but for wildlife habitat, recreational areas, visually pleasing landscapes, and water management.

2-2 Physical and Chemical Characteristics

To assess the energy potential of pine-site hardwoods, it is necessary to know their specific gravity, moisture content, heat content, and chemical makeup.

Stemwood specific gravity (based on ovendry weight and green volume) ranges from 0.40 in yellow-poplar to 0.67 in post oak. Bark, which constitutes about 18.8 percent of above-ground biomass (foliage excepted) in 6-inch trees ranges in specific gravity from 0.34 in winged elm to 0.64 in blackjack and northern red oaks (table 2-4).

Moisture content of stemwood averages 73.5 percent of ovendry weight (42 percent wet basis); bark averages 67.5 percent moisture content on a dry basis and 40 percent on a wet basis (table 2-4). Yellow-poplar stemwood has highest moisture content at 125.8 percent of ovendry weight (56 percent on a wet basis).

Heats of combustion of stemwood, stembark, branchwood, and branchbark all range from 6,840 to 8,123 Btu per ovendry pound (table 2-5). The averages are as follows:

Tree portion	*Heat of combustion (higher heating value)*
	Btu/ovendry pound
Stemwood	7,827
Branchwood	7,784
Stembark	7,593
Branchbark	7,632

About 50 percent of the wood and bark of these hardwoods is comprised of the element carbon, from

Table 2-4.—*Specific gravity, moisture content, and green wood weight of stemwood and bark from 6-inch hardwoods on southern pine sites*

Species	Percent of total volume[1]	Stemwood specific gravity[2]	Stembark specific gravity[2]	Stemwood moisture content[3]	Stembark moisture content[3]	Weight of bark-free green stemwood
				Percent		*Pounds/cu. ft.*
Ash, green	0.9	0.561	0.407	47.4	75.9	51.6
Ash, white		.582	.397	47.5	68.4	53.6
Elm, American	1.4	.536	.395	75.5	86.9	58.7
Elm, winged		.623	.341	65.6	76.0	64.4
Hackberry	.1	.525	.601	72.6	55.5	56.5
Hickory, true	8.5	.643	.522	51.5	72.9	60.8
Maple, red	3.6	.496	.535	69.9	74.4	52.6
Oak, black	4.0	.620	.612	69.2	56.2	65.5
Oak, blackjack	< .1	.638	.642	74.2	43.6	69.4
Oak, cherrybark	1.2	.633	.622	66.6	54.1	65.8
Oak, chestnut	4.2	[4]	[4]	[4]	[4]	[4]
Oak, laurel	1.4	.582	.630	74.4	57.4	63.3
Oak, northern red	2.4	.605	.644	69.7	55.7	64.1
Oak, post	7.0	.659	.498	65.6	48.9	68.1
Oak, scarlet	3.6	.622	.618	69.4	55.6	65.7
Oak, Shumard	.2	.625	.644	69.1	52.2	65.9
Oak, southern red	8.1	609	.601	70.1	52.9	64.6
Oak, water	4.7	.587	.628	73.6	54.4	63.6
Oak, white	12.3	.665	.543	61.9	58.1	67.2
Sweetbay	.6	.437	.440	100.8	102.1	54.8
Sweetgum	13.2	.453	.369	120.4	89.3	62.3
Tupelo, black	5.5	.500	.428	90.0	69.8	59.3
Yellow-poplar	7.0	.395	.390	111.7	125.8	52.2
Other hardwoods	10.1	—	—	—	—	—
	100.0					

[1] Data from Christopher et al. (1976)

[2] Basis of ovendry weight and volume when green. Data from Manwiller, F. G. (in press). Wood and bark specific gravity of small diameter pine-site hardwoods in the South. Forest Products Journal.

[3] Dry weight basis. Data from Manwiller (1975).

[4] Data not available.

Table 2-5.—*Heat of combustion of ovendry wood and bark of 23 southern hardwoods*[1,2]

Species	Stemwood	Branchwood	Stembark	Branchbark
	Btu per ovendry pound			
Ash, green	7,695	7,727	7,472	7,606
Ash, white	8,033	8,013	7,695	7,816
Elm, American	7,770	7,857	6,840	6,904
Elm, winged	7,917	7,869	7,019	6,889
Hackberry	7,882	7,867	7,147	7,141
Hickory, true	8,183	7,931	7,586	7,259
Maple, red	7,846	7,829	7,595	7,384
Oak, black	7,680	7,692	7,642	7,847
Oak, blackjack	7,739	7,739	7,766	7,907
Oak, cherrybark	7,848	7,737	7,582	7,655
Oak, chestnut	[3]	[3]	[3]	[3]
Oak, laurel	7,828	7,653	7,897	7,806
Oak, northern red	7,791	7,776	7,879	7,926
Oak, post	7,889	7,845	7,191	7,728
Oak, scarlet	7,798	7,673	8,041	7,894
Oak, Shumard	7,789	7,745	7,970	7,913
Oak, southern red	7,919	7,839	7,983	7,798
Oak, water	7,876	7,833	7,930	7,918
Oak, white	7,676	7,507	7,328	7,574
Sweetbay	7,736	7,802	7,822	7,886
Sweetgum	7,667	7,690	7,200	7,214
Tupelo, black	7,867	7,814	7,788	8,176
Yellow-poplar	7,774	7,811	7,696	7,666
Average value	7,827	7,784	7,593	7,632

[1] Higher heating value

[2] F. Manwiller, data on file at the Southern For. Exp. Sta., Pineville, La.

[3] Data not available.

30 to 44 percent is oxygen, and about 6 percent is hydrogen. Together, ash and nitrogen amount to about 1 percent of wood weight; ash content in bark is more than that in wood (table 2-6).

The proximate analyses for different hardwood species also fall within a rather narrow range of values (table 2-7). In general, when wood and bark are burned, 75 to 80 percent will burn in the gaseous state while about 20 to 24 percent will burn as fixed carbon (Arola 1976).

Summative chemical analyses of stemwood of 18 of the principal pine-site hardwoods are given in table 2-8. Percentages of the componenets range as follows:

Component	*Percent*
Cellulose	33.8 - 48.7
Hemicellulose	23.2 - 37.7
Lignin	19.1 - 30.3
Extractives	1.1 - 9.6
Ash	.1 - 1.3
	100

Table 2-6.—*Typical ultimate analysis for hardwood species*[1]

	Wood	Bark
	Percent	
Carbon	50.8	51.2
Oxygen	41.8	37.9
Hydrogen	6.4	6.0
Nitrogen	.4	.4
Ash	.9	5.2

[1] Data from Arola (1976).

Table 2-7.—*Typical proximate analysis for hardwoods*[1]

	Volatile matter	Fixed carbon	Ash[2]
		Percent	
Wood	77.3	19.4	3.4
Bark	76.7	18.6	4.6

[1] Data from Arola (1976).

[2] Differs from value in ultimate analysis due to different purpose and method of determination.

Table 2-8.—*Summative chemical analyses of principal hardwoods that grow on southern pine sites* (unpublished data from H. L. Hergert, ITT Rayonier, New York, N.Y.)

Species	Site[1]	Cellulose[2]	Hemicellulose[3]	Lignin[4]	Extractives[5]	Ash[6]
		Percent				
Ash, white	G	48.7	23.5	23.3	5.4	0.3
Ash, white[7]	T	39.5	29.1	24.8	6.3	.3
Elm, American[8]	G	42.6	26.9	22.4	1.9	.8
Elm, American[7]	G	38.0	32.5	24.7	4.6	.3
Elm, American[7]	T	41.9	29.7	25.6	2.4	.5
Hickory, mockernut	T	43.5	27.7	23.6	5.0	.4
Hickory, mockernut (?)	G	37.7	29.2	23.0	9.0	1.1
Hickory, pignut	T	46.2	26.7	23.2	3.4	.6
Maple, red	G	39.9	28.2	23.0	8.6	.3
Maple, red	T	40.7	30.4	23.3	5.3	.3
Oak, black	T	39.6	28.4	25.3	6.3	.5
Oak, blackjack	T	33.8	28.2	30.1	6.6	1.3
Oak, chestnut	T	40.8	29.9	22.3	6.6	.4
Oak, northern red	T	42.2	33.1	20.2	4.4	.2
Oak, post	G	37.7	29.9	26.1	5.8	.5
Oak, post	?	40.3	28.6	25.4	5.1	.5
Oak, scarlet	T	43.2	29.2	20.9	6.6	.1
Oak, southern red	G	40.5	24.2	23.6	9.6	.5
Oak, southern red	?	43.9	27.6	23.0	5.2	.3
Oak, water	G	41.6	34.8	19.1	4.3	.3
Oak, white	G	43.7	24.2	24.3	5.4	1.0
Oak, white	T	41.7	28.4	24.6	5.3	.2
Sweetbay	G	44.2	37.7	24.1	3.9	.2
Sweetgum[8]	G	42.8	30.1	25.7	1.1	.3
Sweetgum[9]	G	43.4	31.0	23.7	1.6	.3
Sweetgum	T	40.8	30.7	22.4	5.9	.2
Tupelo, black	G	44.9	23.2	28.9	2.6	.4
Tupelo, black	T	42.6	27.3	26.6	2.9	.6
Yellow-poplar	T	39.1	28.0	30.3	2.4	.3

[1] G indicates southeastern Georgia; T indicates eastern Tennessee.

[2] 99 percent of glucan percentage minus half the mannan percentage.

[3] Glucomannan plus acetyglucuronoxylan, plus aribinogalactan, plus pectin.

[4] Klason lignin, insoluble and soluble (by ultraviolet spectrum of filtrate, corrected for furfural and hydroxymethylfurfural).

[5] Extracted in succession with petroleum ether, ethyl ether or chloroform, 95-percent ethanol, and hot water.

[6] Ashed at 550°C.

[7] Single tree; dimensions not recorded.

[8] 20 trees.

[9] Single tree, 18 cm diameter, 39 years old.

CHAPTER 3

Direct Combustion

Today, as in the past, the most common way to use wood and bark for energy is to burn it for heat. In the United States the use of wood for fuel peaked about 1875 and has dramaticcally declined with the availability of fossil fuels (Corder 1973). Internationally, however, about half of all harvested wood is still used for fuel.[1] And, with the depletion of fossil fuels, there is renewed interest in using wood and bark as fuel.

3-1 Wood as Fuel

Heating value, ultimate analysis, proximate analysis, moisture content, and size are some of the important characteristics that influence the value of wood as a fuel. Some of these characteristics will not vary significantly, while others, such as moisture content and size, can vary greatly. Often, fuel preparation will be required to minimize variations and to provide a more homogeneous material for efficient combustion.

The Combustion Process—Combustion is the rapid chemical combination of oxygen with the elements of a fuel that will burn (Babcock and Wilcox Co., 1972). Chemically it is an oxidation process that results in the release of heat energy. The major combustible elements in wood are carbon and hydrogen (table 2-6). The complete oxidation of carbon forms carbon dioxide (CO_2), and heat energy; complete oxidation of hydrogen (H_2) yields water (H_2O) and heat energy.

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[1] Saeman, J. F. Energy and materials from the forest biomass. Institute of Gas Technology Symp. on Clean Fuels from Biomass and Wastes. (Orlando, Fla., Jan. 1977.)

$$C + O_2 \rightarrow CO_2 + 14{,}100 \text{ Btu/lb of C} \quad (3\text{-}1)$$

$$2H_2 + O_2 \rightarrow 2H_2O + 61{,}100 \text{ Btu/lb of } H_2 \quad (3\text{-}2)$$

Combustion of wood is not always complete, which results in the release of lesser amounts of carbon monoxide (CO), hydrocarbons, and other substances.

The burning of wood can be divided into three consecutive stages. In the first stage the moisture is evaporated to dry the wood, which requires about 1,100 Btu per lb of water. In the second stage, the temperature of the fuel rises to the point where volatiles are driven off and combusted. In the third stage, the fixed carbon (carbon remaining after the volatiles are driven off) is combusted as fast as oxygen can be brought in contact with it (Fernandes 1976).

In most combustion processes, air is the source of oxygen. For the purpose of calculating the amount of air required for combustion, air can be considered to be 23.1 percent oxygen and 76.9 percent nitrogen by weight. Thus, for every lb of oxygen required, 4.32 lb of air must be supplied. As carbon has an atomic weight of 12 and oxygen has a molecular weight of 32, we can see from equation 3-1 that 12 pounds of carbon require 32 pounds of oxygen to produce 44 pounds of carbon dioxide (molecular weight 44). To burn 1 lb of carbon will require 2.67 lb of oxygen. By similar calculations, it can be shown that 8 lb of oxygen are required to burn 1 lb of hydrogen (equation 3-2). The amount of air required to burn a fuel can be calculated from its ultimate analysis. The average hardwood contains about 50.8 percent carbon, 41.8 percent oxygen, and 6.4 percent hydrogen (table 2-6). The nitrogen and ash do not play a significant role in the combustion calculations and can be left out. In calculating the minimum air required to burn wood, the percentage of elements can be based on any weight; here let us use 1 lb of wood.

The oxygen required to burn the carbon =
1 lb wood (0.508 lb C/lb wood) (2.67 lb O_2/lb C) =
1.36 lb O_2

The oxygen required to burn the hydrogen =
1 lb wood (0.064 lb H/lb wood) (8.00 lb O_2/lb H) =
0.512 lb O_2

Thus, total oxygen required = 1.87 lb.

The molecular structure of the average hardwood is already 41.8 percent oxygen (table 2-6). This oxygen as well as oxygen from air will be involved in the formation of CO_2 and H_2O and must be accounted for in the combustion calculations. Thus, the oxygen already in 1 lb of wood = 0.418 lb. The oxygen needed from the air = total oxygen required − oxygen already in wood = 1.87 lb. − 0.42 lb = 1.45 lb. Therefore, total air required = (1.45 lb O_2) (4.32 lb air/lb O_2) = 6.26 lb air.

This minimum amount of air is called *theoretical air* and does not depend on the moisture content of the wood. In theory, combustion of wood generally requires about 6 lb air per lb of wood (Wiley 1976). In practice, *excess air* is provided to ensure complete combustion. This usually runs from 25 to 150 percent over the theoretical air.

We have seen how the ultimate analysis can be used to calculate the air required for burning wood. The proximate fuel analysis is an indication of the relative amounts of volatile material that will be evolved and burned in the second stage of the combustion process. The amount of carbon left after the volatiles leave is called the fixed carbon. The fixed carbon burns in the solid state. Seventy-seven percent of the average hardwood will burn as volatile matter and 19 percent will burn in the solid state as fixed carbon (table 2-7). This kind of analysis can suggest the best locations for combustion air inlets in a furnace.

Moisture Content and Available Heat—The *heat of combustion* for wood can vary considerably with chemical content. Resin, waxes, lignin, and such compounds with high carbon and hydrogen contents have higher heating values than carbohydrates which have a high oxygen content. Softwoods, because they generally have a higher resin and lignin content, have a higher heat of combustion than hardwoods. For example, loblolly pine stemwood has a heat of combustion of 8,600 Btu per ovendry lb (Howard 1973), while pine-site hardwoods average 7,827 Btu per ovendry lb of stemwood and about 7,593 Btu per ovendry pound of stembark (table 2-5).

Heats of combustion are determined with an oxygen bomb calorimeter. Values obtained are somewhat higher than those recovered in practice because the calorimeter is closed and the products of combustion are contained. Thus, on cooling, water vapor is condensed and releases its heat of vaporization. In an industrial furnance, this heat is normally lost to the atmosphere. The heat of combustion measured by a bomb calorimeter is called the *higher heating value*. The *lower heating value* is obtained by subtracting the heat of vaporization of the water formed in combustion. The average lower heating value for pine-site hardwoods is 7,261 Btu per lb for stemwood and 7,027 Btu per lb for stembark.

There are two ways to express moisture content of wood. The ovendry method is most commonly used by people in the forest products industry.

$$\text{M.C. (dry)} = \frac{\text{(weight of water)}}{\text{(weight of ovendry wood)}} \times 100 \qquad (3\text{-}3)$$

People in the field of fuels and combustion and most engineers use the wet basis moisture content.

$$\text{M.C. (wet)} = \frac{\text{(weight of water)}}{\text{(total weight of wood and water)}} \times 100 \qquad (3\text{-}4)$$

A material that is half water and half wood would have M.C. (dry) = 100 percent and M.C. (wet) = 50 percent. The two moisture contents can be converted by the following formula:

$$\text{M.C. (wet)} = 100 \text{ M.C. (dry)}/[100 + \text{M.C. (dry)}] \qquad (3\text{-}5)$$

$$\text{M.C. (dry)} = 100 \text{ M.C. (wet)}/[100 - \text{M.C. (wet)}] \qquad (3\text{-}6)$$

In keeping with most of the literature referenced, the wet basis moisture content will be used in the following discussion unless otherwise noted.

The economic value of a fuel will depend both on its heating value and moisture content. High moisture content is detrimental in two ways. First, it reduces the *available heat* of the fuel. The higher heating value of a fuel does not change with increasing moisture content, but the available heat does change (equation 3-7) because there is simply less fuel per unit weight (table 3-1, Ince 1977).

$$\text{Available heat} = \text{(percent wood)} \times \text{(higher heating value)} \qquad (3\text{-}7)$$

High moisture content also reduces furnance efficency, because heat energy is lost up the stack in vaporizing the moisture in the wood. Vaporization of fuel moisture is the first stage in combustion; thus heat energy must raise the moisture temperature from ambient (70°F) to the boiling point (212°F). Additional heat energy is required to vaporize the water to steam at 212°F. Heat energy is also lost in raising the steam temperature to that of the furnace stack gases. Steam tables can be readily used to calculate the amount of energy required to heat and evaporate water. For example, if the stack temperature is 500°F, the calculated heat energy lost in changing the water at 70°F to steam at 500°F and 14.7 psi is 1,250 Btu/lb of water (Wiley 1976).

Table 3-1.—*Available heat versus moisture content for pine-site hardwoods*[1]

Moisture content	Available heat (Higher heating value)
Percent (wet basis)	*Btu/lb*
0 (ovendry)	7,827
10	7,044
25	5,870
42	4,540
50	3,914

[1] Average value for stemwood (table 2-5).

Fuel Preparation—High moisture content, bulkiness, dirt, and heterogeneous size are the undesirable properties that come with using some wood fuels. As with refined petroleum fuels, wood can be upgraded in value for various burning situations (Johnson 1975). Wood-burning furnaces, for example, are designed to burn chip size or smaller material. This permits automation in feeding and more efficient burning. But of course the size of pieces can range from slabs and logs to sawdust and shavings. To reduce and size wood for easier handling and burning, it usually is passed through an attrition mill or *hog.* In a typical hammer hog (fig. 3-1), large pieces enter at the top and are forced down and through spaced bars by the rotating action of hammers. The size of the particles leaving the hog depends on speed of the hammers and clearance between the hammers and the spaced bars. Optimum particle size depends on the burner. In some grate-type furnaces, for example, an excess of fines and sawdust inhibits efficient combustion.

Hogged fuel is wood waste having no higher recovery value than that of fuel; such fuel contains no municipal refuse (Johnson 1975). Under this broad definition, which is in common use today, a fuel would not have to be passed through a hog to be called hogged fuel. Common hogged fuels include sander dust, shavings, sawdust, bark, log yard cleanup, clarifier sludge, forest residuals, and fly carbon.

Boiler tests have shown that drying hogged fuel produces the double benefit of increased steam generation efficiency and reduced emissions (Johnson 1975, Hall et al. 1976). Most furnaces designed for wet wood operate best if weight of water does not exceed that of wood, that is, if moisture content is 50 percent or less on a wet basis. At moisture contents exceeding 60 percent, most furnaces operate poorly, if at all.

Wood fuel can be dried in several ways. Mechanical pressing squeezes water out with simple equipment that requires no heat. Moisture content can be reduced to 50-55 percent by this method (Porter and Robinson 1976). Air drying is slow but can reduce the moisture content to about 20 percent and if climate permits, even less. Perhaps solar dryers will be

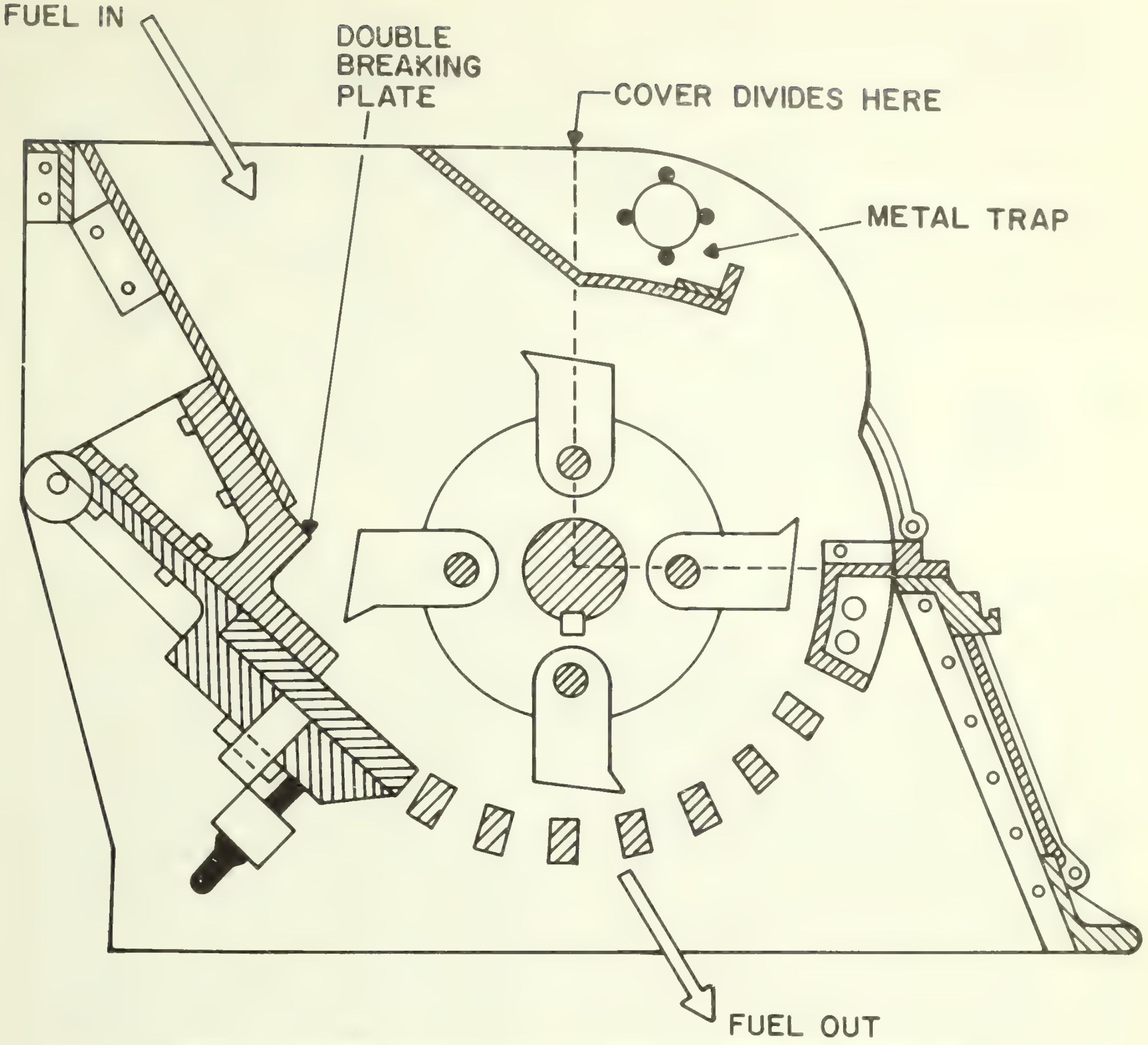

Figure 3-1.—*Transverse section through a typical hammer hog. (Drawing after Fernandes 1976.)*

developed for this purpose. Today, fuel dryers which use hot gases are in widespread use. The most common type is the rotary drum. Other types of fuel dryers, such as the hot hog and hot conveyor system (Johnson 1975) have not been as successful.[2]

In a typical *rotary drum dryer system,* fuel that is to be dried is first screened to remove and rehog oversized pieces. Hot gases and the fuel enter one end of the drum or cylinder and are brought into contact with each other by cylinder rotation and horizontal gas flow (fig. 3-2). An induced-draft fan draws the hot gases through the dryer, and this gas pushes the dried fuel toward the outlet end of the dryer. Two- to four-inch pieces can be adequately dried in 20 minutes or less. Fuel is separated into different sizes at the dryer outlet. Airborne fines go to the cyclone separator with the gas flow (Thompson 1975, Johnson 1975).

Rotary drum dryers are suited for handling large quantities of wet fuel. The inlet temperature can go as high as 1600°F if the moisture in the fuel is high enough to absorb the heat without scorching the wood. However, one must be careful to prevent the formation of blue haze. Blue haze, a major environmental concern for the forest products industry, is caused by distillation of organic material such as terpenoids into the air while drying wood. Douglas-

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[2] Personal communication with David C. Junge, Oregon State University, Corvallis.

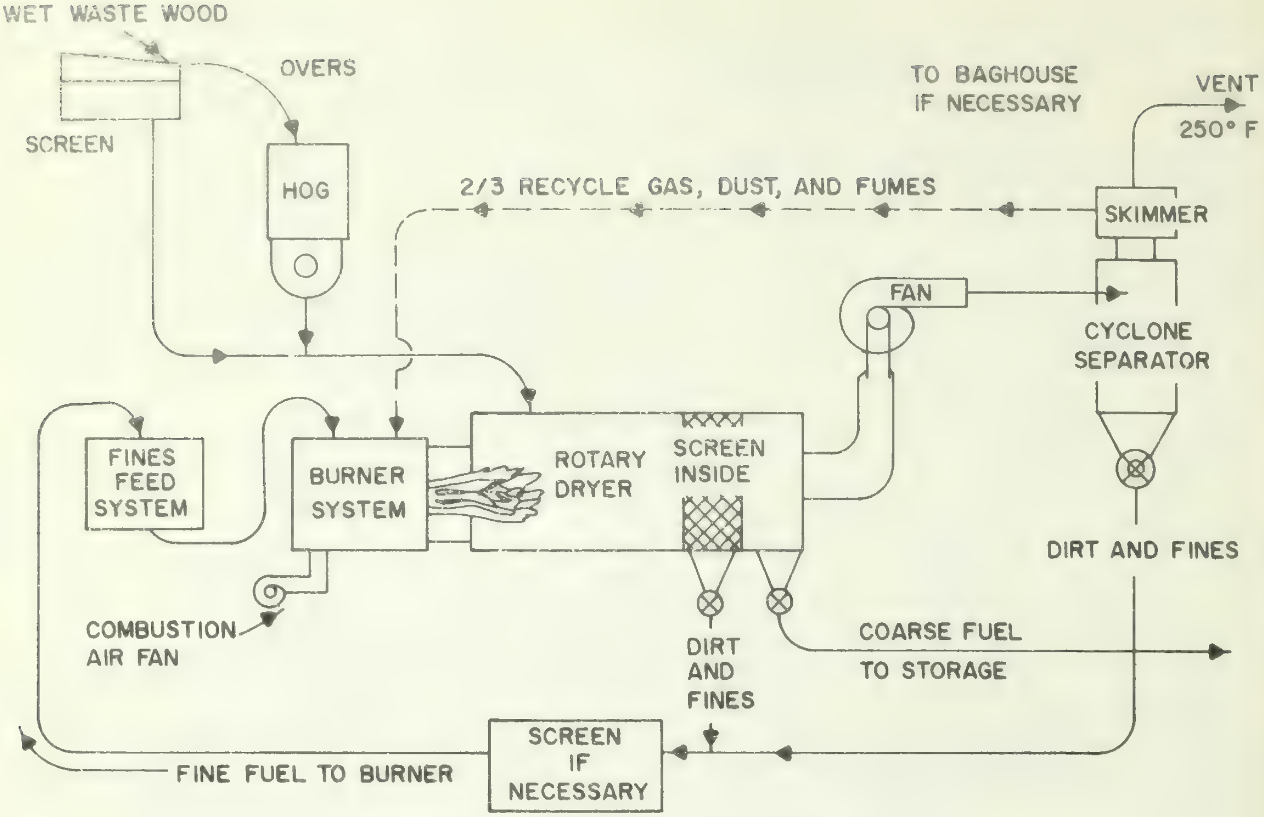

Figure 3-2.—*Typical rotary dryer system. (Drawing after Johnson 1975.)*

fir dried above 750°F creates blue haze. We do not know the optimum drying conditions for pine-site-hardwoods.

Bulkiness of wood fuel can be circumvented to some extent by compressing it into more dense material of various shapes and sizes. Such compressing makes storing, handling, and shipping easier and promotes uniform burning.

There are several ways to densify wood for fuel. Compression baling can reduce wood residue volume to one-fifth its loose bulk while squeezing out 12 to 15 percent of its moisture (American Hoist & Derrick 1976). Most of the densified products can be formed by compressing the residue in a die under heat and pressure. Apparently the key to success is to break down the elasticity of the wood or bark. If the elasticity is not sufficiently destroyed, the densified form will not have permanence (Hausmann 1974). It is possible that polyphenolic compounds (especially in bark) play a role in successful densification. The compounds may act as natural binding agents or glues when subjected to heat and pressure. Fire logs for home use can employ a wax or other binder (Braun 1975).

The technology for densifying particulate wood and bark has been around for over 50 years (Sprout Waldron and Co. 1961, Hausmann 1974, Currier 1977, Farnsworth 1977). The famous "pres-to-logs" used for hand-firing fireplaces and stoves were first made about 1933. In the 1950's machines were developed to extrude wood residue rods suitable for fueling coal stoker furnaces. Generally, the rods are about 1 inch in diameter and can be cut to desired lengths. In 1959 a company in Tennessee first pelletized bark for fuel. These oak bark pellets were used with coal to fire a steam boiler and reportedly gave burning rates equivalent to soft-coal. Since the late 1960's extensive research on pelletization of wood and bark residues for fuel and other uses has been carried out by Currier (1977) at Oregon State University and Steffensen (1973) at Georgia-Pacific.

Pelletization can be accomplished with standard agricultural pellet mills (Currier 1977). The product is generally 3/16- to 1/2-inch in diameter and 1/2-inch long. The compression ratio in pelletizing is usually about 3 to 1. Because of their uniform density, fuel pellets are easier than hogged fuel to meter into a furnace and can be burned at more closely controlled rates. Wet fuel cannot be pelletized unless it is first dried, however, and part of such fuel must be used to dry the material to be pelletized. Because of this, those industries that have dry wood wastes, such as furniture and cabinet manufacturers, may find pelletizing most economically attractive.

A company in Alabama pelletizes sawdust and bark after pre-drying it in a rotary dryer fired by some of the pelletized product. The pellets are sold to a power plant. Estimated total investment is about one-half million dollars including land. The pelletizer sells for around $32,000. Similar estimates of cost have been reported by Farnsworth (1977). A company in Oregon markets pelletized Douglas-fir bark (Blackman 1978). Reportedly, the product sells for about half the price of coal of equivalent Btu's. Plant operations use the equivalent of 12 percent of the energy contained in the pelletized product.

Residues—Ash and incompletely combusted carbon are the solid residues from burning wood. In boiler furnaces, where high burning temperatures are achieved, slag and clinker are formed from the melting and fusion of ash. Analysis of the ash from the 23 pine site hardwoods is underway at the Southern Forest Experiment Station. Studies of other species indicate that wood ash is composed primarily of calcium oxide (CaO) and silica (SiO_2) and contains small percentages of alumina (Al_2O_3), iron oxide (Fe_2O_3) and magnesium oxide (MgO) (table 3-2).

Wood ash generally has been considered inert (Hall et al. 1976), but this may not be chemically true. In at least one case, wood ash has been shown to be an effective catalyst in the gasification of wood (Feldman 1978).

Increased use of wood for fuel might make ash disposal a problem (Hall et al. 1976). Perhaps ash could be used as a soil conditioner to break up clay, and the alkalinity of ash could help raise the pH of acid soil. If supplemented with nitrogen compounds ash also has the potential to be used as a fertilizer. One mill in central Louisiana uses clinkers for roadbed surfaces around the plant.

Emissions—Both gaseous and particulate emissions occur when wood is burned (table 3-3). Carbon dioxide and water vapor (equations 3-1 and 3-2) combined with nitrogen and oxygen from the combustion air comprise 98-99 percent of the total material emitted from an efficient combustion process.

In terms of potential air pollution, the United States Environmental Protection Agency (EPA) is concerned with the amounts of particulate matter, sulfur dioxide, carbon monoxide, nitrogen oxides, and unburned hydrocarbons that are emitted into the atmosphere. In wood combustion, sulfur dioxide emission is negligible, and carbon monoxide and hydrocarbon emissions present no problems in most situations. The situation with nitrogen oxides is less certain, and particulate emissions from wood-fired boilers require attention.

When combustion is poor, hydrocarbon[3] emissions are increased. In extreme cases, these emissions may be 55-85 lb/ton of fuel (Junge and Kwan 1974). High hydrocarbon emissions could present a twofold pollution problem. First, polycyclic aromatic compounds can be produced through the incomplete combustion of solid carbonaceous fuels such as coal (Hall et al. 1976). Certain polycyclic aromatic compounds are suspected carcinogens. However, it is not certain to what extent these compounds occur in the incomplete combustion of wood. The second problem is the production of peroxy compounds that react with sunlight as part of the complex process resulting in photochemical smog. Formation of carcinogenic compounds or photochemical smog should not be problems in wood burning if combustion is efficient (Hall et al. 1976).

Nitrogen oxides (NO and NO_2) are instrumental in smog formation. At present, the automobile engine

Table 3-2.—*Chemical composition of wood ash*[1]

Component	Percent by weight
SiO_2	33.8
Al_2O_3	2.6
TiO_2	.2
Fe_2O_3	1.6
CaO	56.5
MgO	4.7
Na_2O	.5
K_2O	.1
	100.0

Data from Babcock and Wilcox Company (1972).

Table 3-3.—*Emissions from combustion of hogged fuel (Junge 1975a)*

Gases		Particulate matter
Nitrogen	98-99% of total	Inorganic flyash
Carbon dioxide		Fixed carbon
Oxygen		Traces of metals and salts
Water vapor		
Carbon monoxide		
Unburned hydrocarbons		
Sulfur dioxide		
Oxides of nitrogen		
Inert gases		

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[3] The term hydrocarbon is poorly defined as it is used in the literature and is sometimes used to denote oxygen-containing organic compounds as well as hydrocarbons.

is by far the largest source of nitrogen oxides. In high concentrations, these compounds not only harm life but destroy material as well. Fortunately, the ambient concentration of nitrogen oxides is low enough in most areas that emission control for them from wood burning should not be required. However, if the need arises, modification in the combustion process rather than the use of a cleaning device at the stack would be necessary (Hall et al. 1976).

Particulate emissions can be controlled by any of four basic devices. These are cyclone separators, scrubbers, baghouse filters, and electrostatic precipitators (Junge 1975a). Most wood-fueled boilers are equipped with cyclone separators; however, some are equipped with scrubbers.

Comparison to Fossil Fuels.—The higher percentages of oxygen in the molecular structures of wood and bark gives them lower heating values than coal and oil (table 3-4). In comparison with coal, wood has a low ash content and little or no sulfur. The chief drawback of woody fuels is their naturally high moisture content and bulkiness.

Arola (1975) has a graph (fig. 3-3) that is a useful tool for comparing the cost of heat or steam produced from wood-based and fossil fuels (See below for an example of how to use the figure.)

The graph has three sets of lines which correspond to three classes of fuel considered: (1) oil; (2) coal, bark, wood, and municipal solid refuse; and (3) gas. A fourth set of lines represents efficiency values to allow for losses when converting heat energy to steam. Heating values used for the solid fuels are "as fired," that is, the available heat at the moisture content (wet basis) as fired (equation 3-7).

Figure 3-4 is an example of how to use the graph (Arola 1975).

Given: The fuel is bark which costs $10/wet ton and has a higher heating value of 9,000 Btu/lb when ovendry. Process efficiency is 65 percent. The bark is fired at 50 percent moisture content (wet basis).

Problem: What is the cost of steam?

Solution: Available heat at 50 percent moisture content is 4,500 Btu/lb, i.e., (1.00 - 0.50) x 9,000 Btu/lb. From the $10/ton point along the upper scale at bottom of chart, extend a line vertically to the 4,500 Btu/lb point for bark (interpolation required). Extend a horizontal line from this intersection to the 65 percent efficiency line and then a vertical line to the top of the graph to read the cost of steam.

Answer: About $1.70/million Btu.

3-2 Industrial Burning Systems

Today industrial wood burning furnaces are commonly incorporated into boiler systems to produce steam. Nearly 1700 such wood fired boiler systems are in operation in the United States (Environmental Protection Agency 1977). They range in size from shop-fabricated units, with steam capacities up to about 100,000 pounds per hour, to large field-erected units that can generate up to 600,000 pounds of steam per hour on hogged fuel (U.S. Forest Service 1976, Bliss and Blake 1977). Wood-fired boilers that produce 15,000 to 100,000 pounds per hour of steam are the most common recent installations (Hall et al. 1976). In some furnace systems the hot combustion gases produced are used to direct-fire kilns and dryers without the intermediate step of steam generation. In addition, certain furnaces could be used to drive gas turbines whose exhaust heat could then be

Table 3-4.—*Ultimate analyses and heating values of some fossil fuels compared with hardwoods*

	Coal[1]		Hardwood[2]		Residual fuel oil[1]
	Western	Pennsylvania	Wood	Bark	
	Percent				
Ultimate analysis					
Hydrogen	6.4	5.0	6.4	6.0	9.5 - 12.0
Carbon	54.6	74.2	50.8	51.2	86.5 - 90.2
Oxygen	33.8	7.1	41.8	37.9	–
Sulfur	.4	2.1	–	–	.7 - 3.5
Nitrogen	1.0	1.5	.4	.4	–
Ash	3.3	10.1	.9	5.2	.01- .50
Heating value, Btu/lb	9,420	13,310	7,827[3]	7,593[3]	17,410 -18,990

[1] Data from Hall et al. (1976).

[2] Data from Arola (1976).

[3] Data from table 2-5.

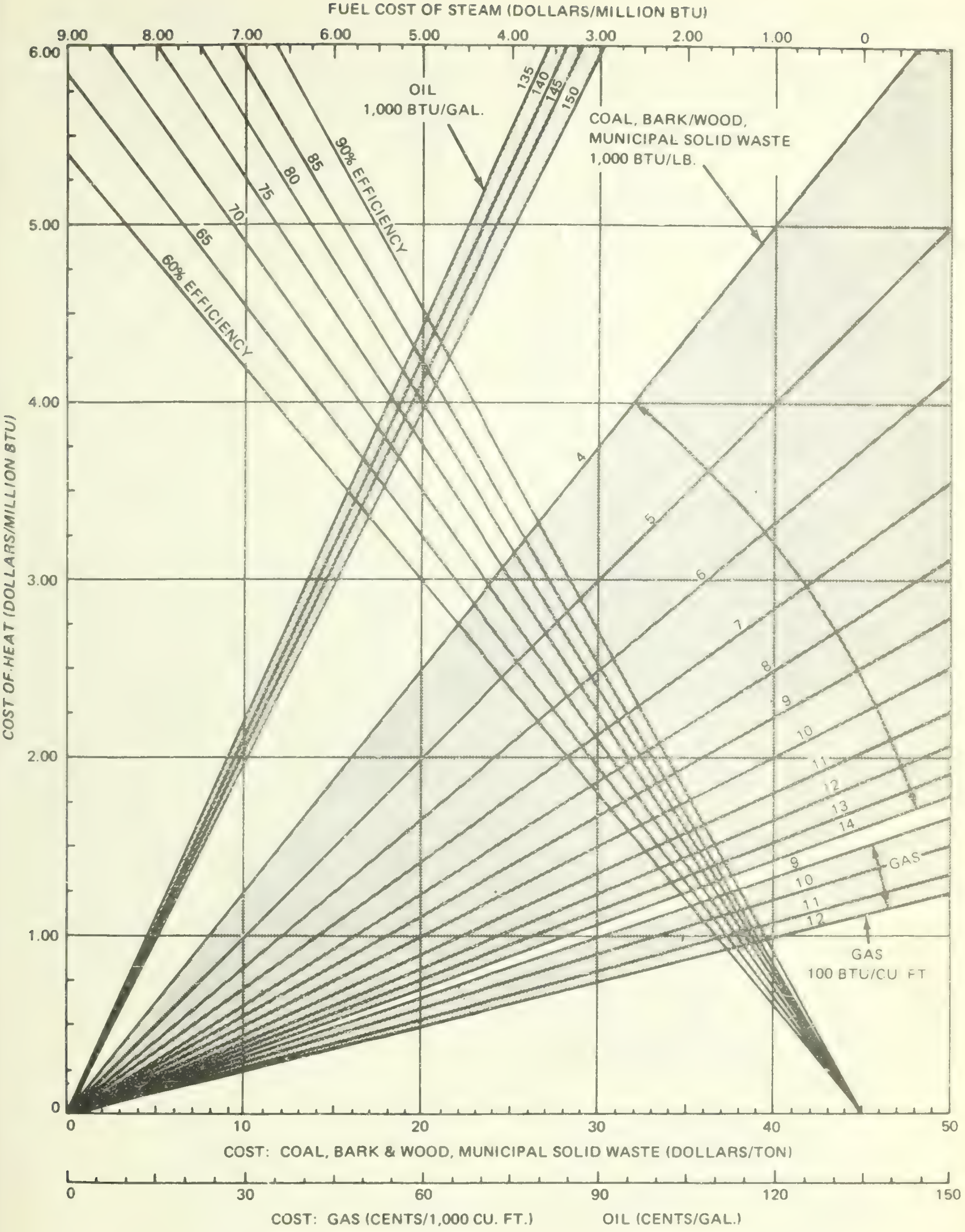

Figure 3-3.—*Graph to compare fuel value for wood-based and fossil fuels. (Drawing after Arola 1975.)*

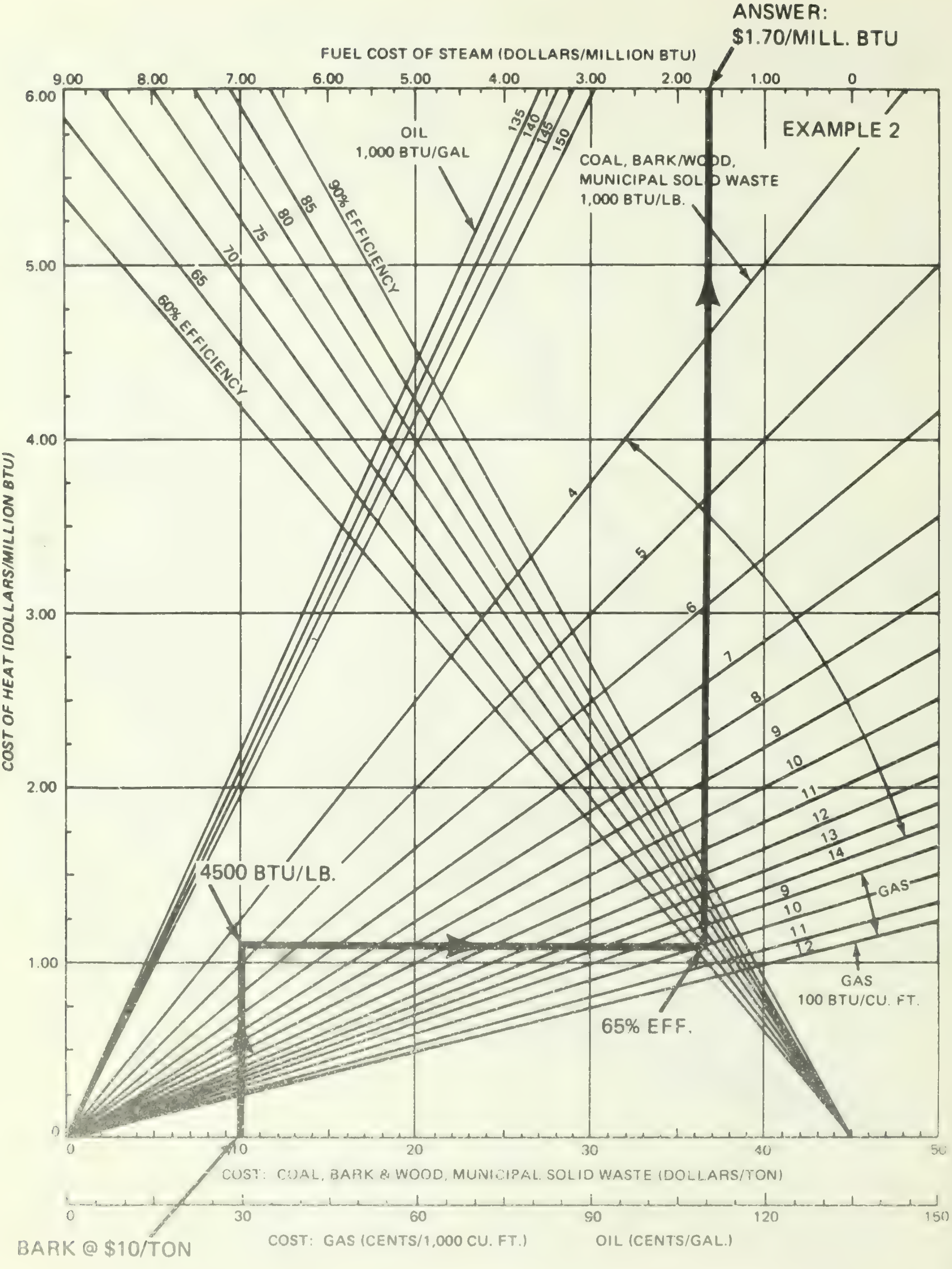

Figure 3-4.—*Example of how to use the fuel value comparison graph. (Drawing after Arola 1975.)*

used in a conventional boiler to produce added steam power.[4]

Basically there are two classes of furnace design in use for wood burning—grate burners and suspension burners. Dutch ovens, inclined grate furnaces and spreader stokers burn the fuel on a grate, either in a pile or spread into a thin bed. In suspension burning, the fuel is supported by air during its combustion. Within these two classes of furnace design are a variety of furnace types which can differ markedly in basic operation. This variety is due largely to the various forms that wood fuel can take. Innovative engineers have created a diversity of furnaces designed for particular circumstances.

Dutch Ovens.—Historically, Dutch ovens (fig. 3-5) provided steam for many industries in this country. They are now considered obsolete for new installations, because they are expensive to maintain and respond poorly to load changes.

The Dutch oven is a two-stage refractory (firebrick-lined) furnace. Fuel is fed through a chute in the oven roof and forms a conical pile on the grate in the oven or primary furnace. Here the fuel is dried and partially combusted. The system is designed so that there is insufficient air for complete combustion in the primary furnace. Combustible gases emerge from the fuel pile and pass into the secondary furnace, or combustion chamber, where air entering through the overfire air ports completes combustion. On their way to the stack, the hot combustion gases pass through water-carrying heat exchangers to generate steam. Removal of ash is done by either manual rake-out or dumping grates. Combustion rates of about 600,000 Btu per ft^2 of grate per hour have been attained with air and wood having 45 percent moisture content, but combustion rate drops off rapidly above that level. Excess air at the stack is usually between 30 and 40 percent (Babcock and Wilcox 1972, Junge 1975a).

Fuel Cell Burners.—Fuel cell burners (fig. 3-6) are an adaption of the Dutch oven design; drying and gasification of the fuel occur in the primary furnace, and combustion is completed in the secondary furnace. Fuel is metered into the primary furnace, which is a vertical, refractory-lined cylinder with a water-cooled grate. Here the fuel is partially combusted, and the volatiles pass into the upper chamber where burning is completed. Boilers of this type are common in the western United States, where they are used for kiln-drying lumber. They generally have capacities of 10,000 to 30,000 lb of steam per hour when operated at pressures below 150 psi. Dryers have to be incorporated when fuel moisture content is above 50 percent (Junge 1975a, Corder 1973).

A new variation of a fuel cell furnace is the wet cell burner (Anonymous 1978). This unit employs a cyclonic-type furnace for the upper, secondary combustion chamber (fig. 3-7). Hogged fuel with a moisture content up to 65 percent is metered by a hydraulic ram at a rate controlled by Btu demand. The hydraulic ram then forces the fuel up through

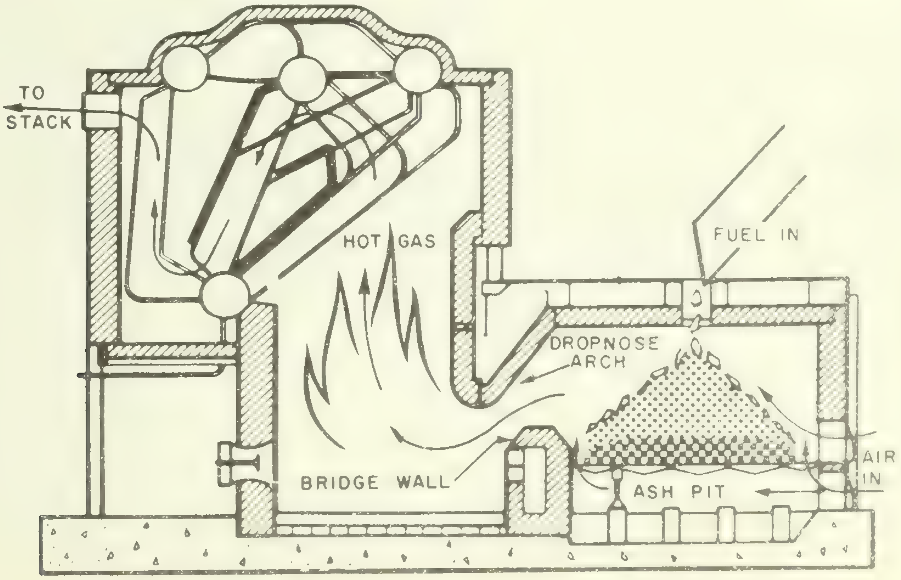

Figure 3-5.—*Dutch oven furnace and boiler. (Drawing after McKenzie 1968.)*

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[4] H. G. Hagen. 1977. Wood fueled combustion cycle gas turbine power plant. 38 p. Paper presented at the California Energy Comm. Energy-From-Wood-Workshop.

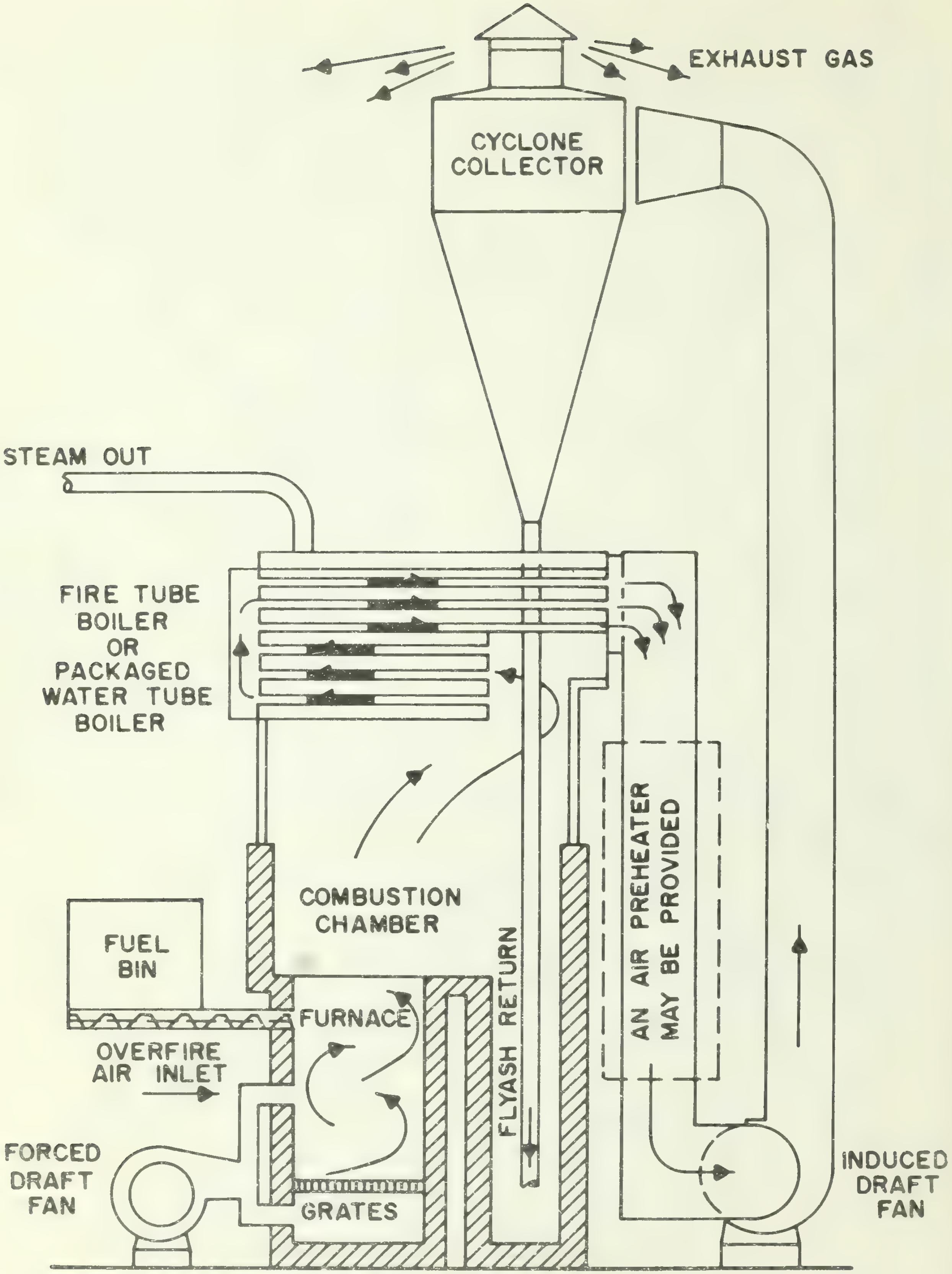

Figure 3-6.—*Fuel cell furnace system. (Drawing after Junge 1975a.)*

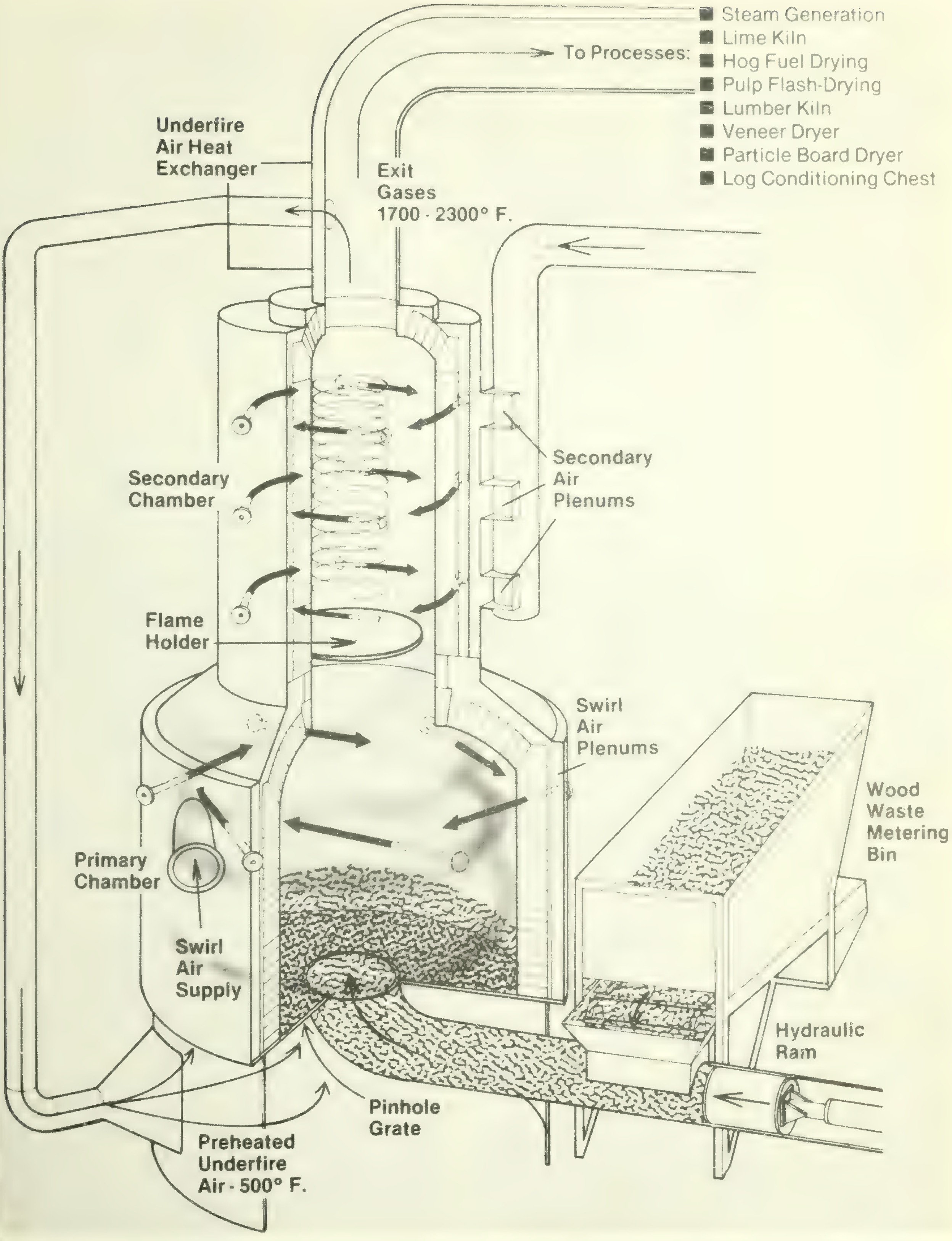

Figure 3-7.—*Wet cell burner. (Drawing from Hugh Dwight Advertising.)*

a large-diameter cylinder under the base of the burner, depositing the fuel through an opening in pinhole grates that form the floor of the lower chamber. The fuel forms a slightly conical pile over the grate as more fuel is pushed up from below. The pile is ignited by an automatic gas burner which shuts down after the pile is burning. Preheated air is forced up through the pile as well as through swirl air plenums above the pile. However, insufficient air for complete combustion is maintained so that the fuel is mostly dried and gasified. Swirling air-flows near the top of the primary combustion chamber subject the hot distillates to a scrubbing action that separates particulates to the outer wall by centrifugal action. The fixed carbon particulates complete oxidation as they are swept away. As the volatiles rise to the upper combustion chamber, they are met by cooler air that is vortexing downward. This action mixes and combusts the gases in a cyclonic air flow. Excess combustion air. is limited to 10-15 percent by this mechanism. Exhaust gases leave the burner at 1,700 to 2,300°F and can be used to fire a boiler or be blended with cooler air to use in kilns and dryers.

Inclined Grate Furnaces.—This type of furnace usually has a water-cooled grate and water-cooled furnace walls (fig. 3-8). Fuel enters the furnace at the top of the grate and is dried as it slides down to the lower horizontal section where it is burned. Ash is removed intermittently through discharge doors. Inclined grate furnaces are one of the more popular types of furnaces in Europe (Astrom and Harris 1975).

Spreader Stokers.—The spreader stoker is probably the most commonly used wood and bark burning furnance (Fuller 1976, Bliss and Blake 1977). These furnaces can burn large amounts of wood and bark alone or in combination with coal, oil, or gas with little difficulty.

In spreader stokers, fuel is spread either pneumatically or mechanically into an even thin bed across the grates. When the fuel is added above the grate, smaller particles and volatiles burn in suspension while the large pieces of fuel fall to the grate and burn in the fuel bed. Flames from the particles suspended above the grate radiate heat that aids in combustion of the fuel bed. Furnace walls are normally lined with heat exchange tubes (water walled). Because there is no refractory to reflect heat back to fuel, combustion air is sometimes preheated (Junge 1975a).

Figure 3-9 shows a closeup sectional view of a travelling grate spreader stoker with front ash discharge; in figure 3-10 the stoker is attached to a large steam generator. Fuel is conveyed continuously and distributed into the furnace through an air-swept spout. High-pressure overfire air jets provide turbulence to aid the suspension burning of small particles and volatiles. Air for combustion in the fuel bed is admitted from the plenum chamber through holes in the grate bars. The fuel bed moves with the grate at a rate adjusted to allow complete combustion of the fuel before the ash is dumped into a hopper. Other types of grate are also used with spreader stoker furnaces (Fuller 1976). These include a vibrating-grate where the fuel bed moves toward the ash hopper as the bed is intermittently vibrated by an eccentric drive mechanism (fig. 3-11). In dumping-grate stokers (fig. 3-12) the grate bars are rotated 90° to dump the ash into a combined ash hopper-air plenum.

Spreader stokers can burn hogged fuel containing 45 to 50 percent moisture at 1 million Btu per hour per ft^2 of grate area while using 35 to 45 percent excess air. However, most boilers in operation use more than 75 percent excess air.[5] Spreader stokers are used with boilers that generate from 25,000 to 600,000 lb of steam per hour (Babcock and Wilcox Co. 1972, Corder 1973, Bliss and Blake 1977).

Suspension-Fired Boilers.—Suspension firing of wood and bark in large boiler furnaces is similar to the firing of pulverized coal (Hall et al. 1976). Most often bark hogged to a small size and pneumatically injected into the furnace is the fuel. If injection is high enough in the furnace and the fuel particles are small enough, then the fuel will be completely combusted before it falls out of the combustion zone.

In the system shown in figure 3-13, turbulence is provided by high velocity, tangentially injected flows of preheated air through nozzles at various heights in the furnace. This is also called tangential firing (Fernandes 1976). In tangential firing, the air flows create spinning air masses or fire circles that hold the fuel particles in suspension while they burn (fig. 3-14). Figure 3-15 shows an actual photograph of the fire circle in a boiler furnace.

In the suspension burners, a small dump grate is located at the bottom of the furnace to catch and burn larger fuel particles that fall out of suspension (Fernandes 1976). Usually, suspension-fired boilers are simpler than spreader stokers, but more extensive hogging of the fuel is required. Bark alone can be used as fuel but usually an auxiliary fuel, such as oil, pulverized coal, or gas is co-fired in suspen-

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[5] Personal communication with David C. Junge, Oregon State University, Corvallis.

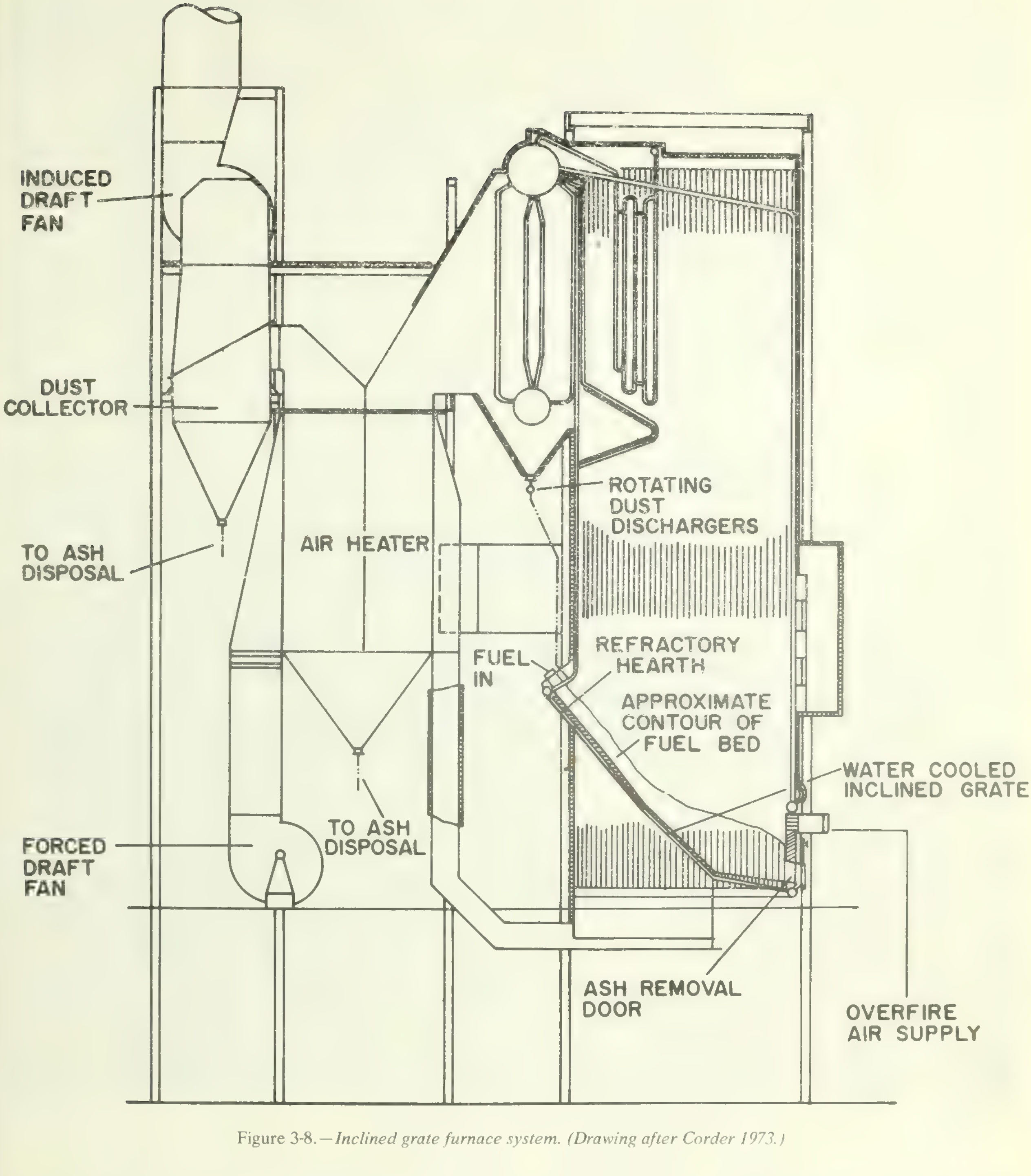
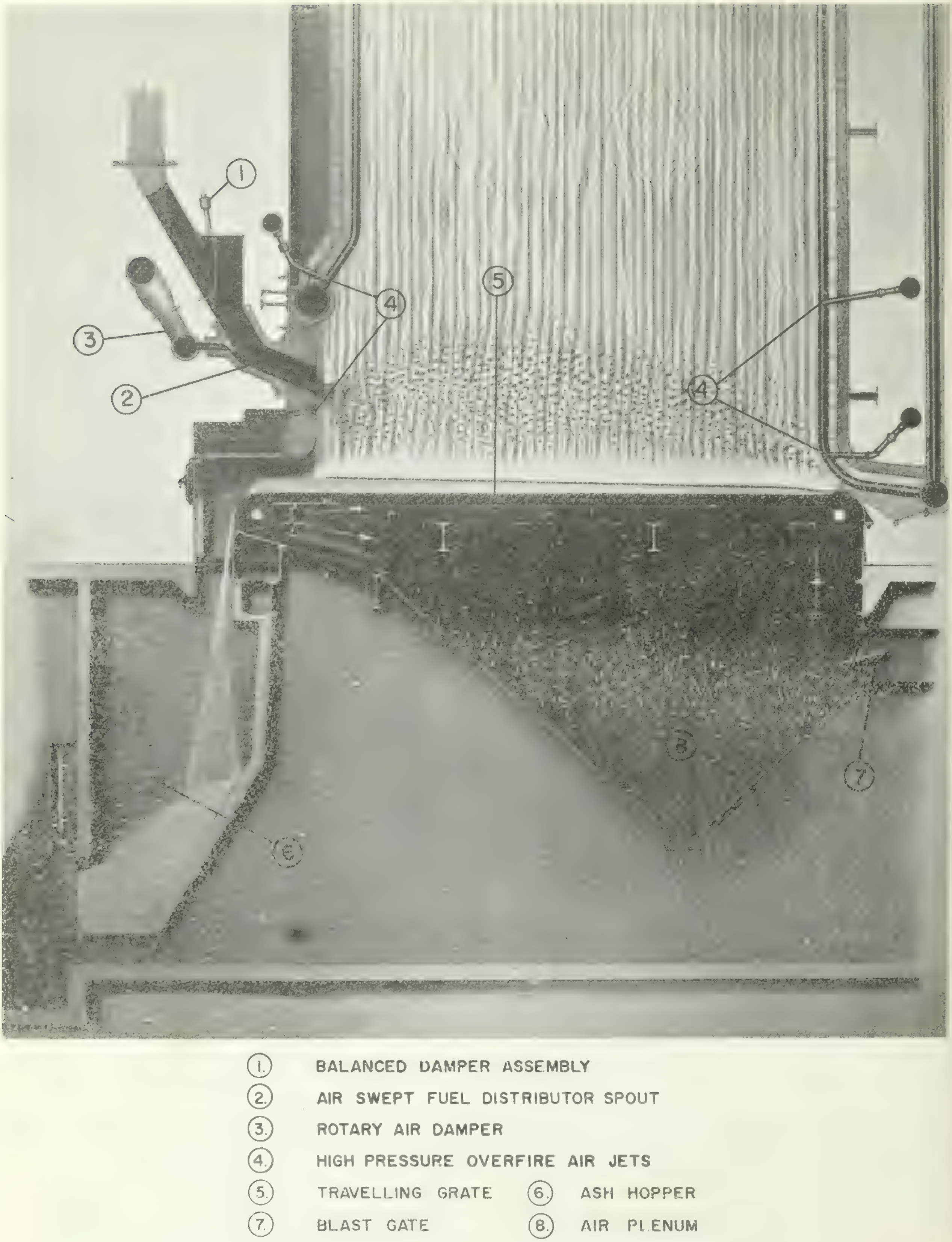


Figure 3-8.—*Inclined grate furnace system. (Drawing after Corder 1973.)*

sion with the bark. Auxiliary fuel nozzles are usually located immediately above and below the bark nozzle. Suspension fired boilers are often large units, some capable of generating over 500,000 lb of steam per hour (Hall et al. 1976).

Cyclonic Furnaces.—Cyclonic furnaces also burn fuel in suspension. In early water-cooled models, cyclone burners were fueled with wood and bark in combination with coal (Fuller 1976). Today, refractory lined models are commonly used and do not require auxiliary fuel except at startup.

In the horizontally mounted cyclonic burner, a drumlike combustion chamber is closed at one end (fig. 3-16). Hot combustion gases are discharged from the opening in the other end called the choke. Combustion air is forced by a blower through the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4
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① BALANCED DAMPER ASSEMBLY
② AIR SWEPT FUEL DISTRIBUTOR SPOUT
③ ROTARY AIR DAMPER
④ HIGH PRESSURE OVERFIRE AIR JETS
⑤ TRAVELLING GRATE
⑥ ASH HOPPER
⑦ BLAST GATE
⑧ AIR PLENUM

Figure 3-9.—*Sectional view of a traveling grate stoker with front ash discharge. (Drawing from Detroit Stoker Company.)*

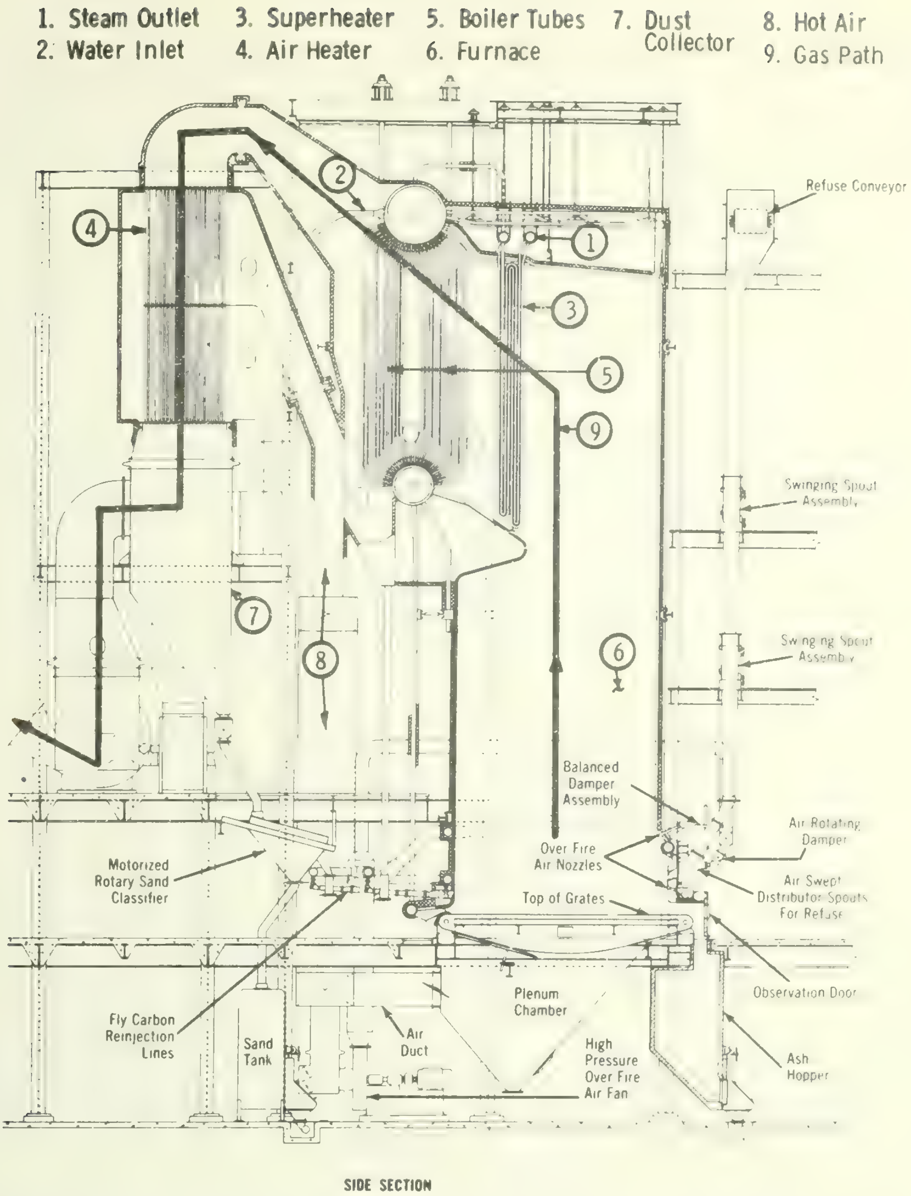

Figure 3-10.—*Components of a typical large steam generator equipped with a spreader stoker. (Drawing from Detroit Stoker Company.)*

air manifold into tuyeres which admit the air tangent to the inner surface of the combustion chamber. The airflow pattern created is a double cyclonic action. Fuel is injected tangentially into the burner with a stream of high velocity air. Mixing of the fuel and air takes place around the periphery of the burner as they traverse toward the choke. Both the high turbulence of the cyclonic airflow and time in the burner contribute to complete combustion as long as proper temperatures are maintained. Excess air can vary from 60 to 130 percent depending on the installation (Levelton and O'Connor 1978).

Fuel wood for this system must be dry (15 percent moisture content) and sized (1/8-inch or less). The fuel is metered from a bin to a mixing tee and then into the high velocity air stream for injection into the burners. An auxiliary burner is required for start-up and additional controls and components can be added for automation. A recirculation system can be incorporated to burn the volatile hydrocarbons associated with the blue haze produced by some veneer dryers (Cherewick 1975, Neild and Weyer 1975). A trap can be added to the basic burners for automatic removal of slag and grit.

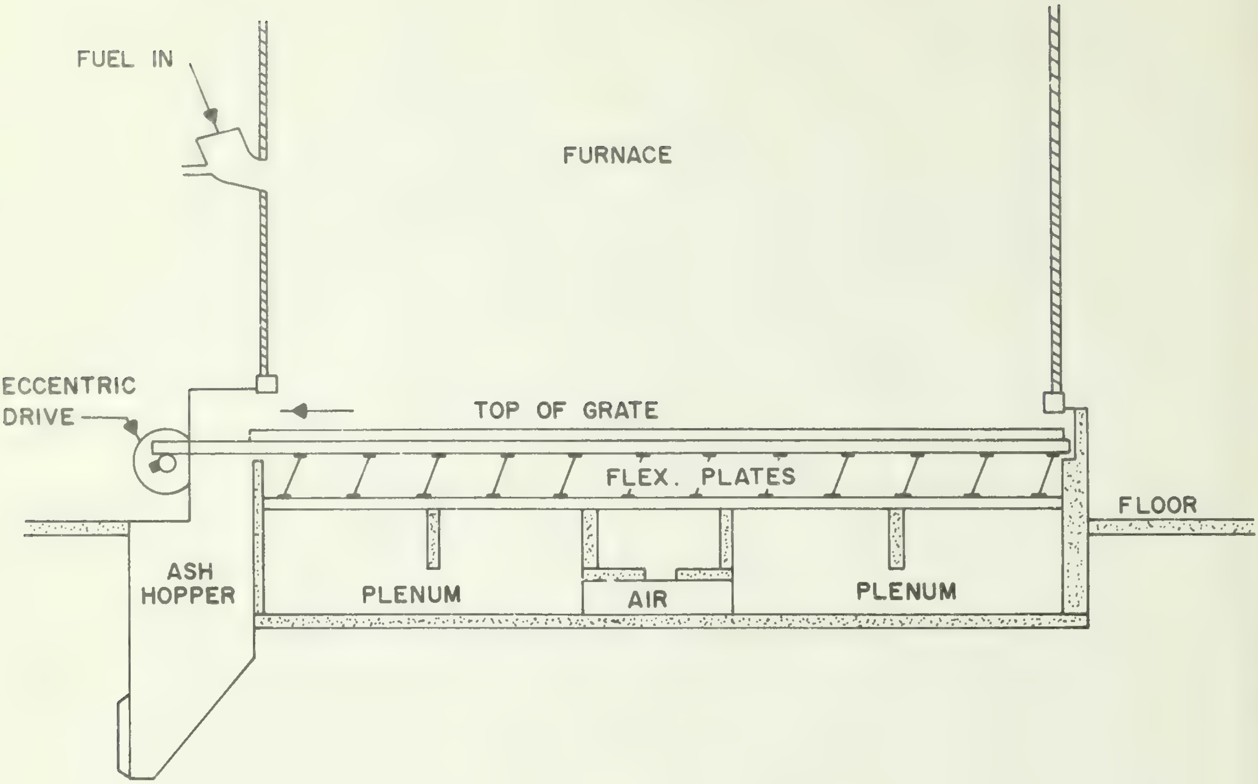

Figure 3-11.—*Vibrating grate stoker. (Drawing after Fuller 1976.)*

Capacities range from 5 to 60 million Btu per hour. Applications for this type of burner include direct firing of lumber kilns, rotary and veneer dryers, and boilers.

Fluidized Bed Burners.—Particles such as sand contained in a vessel can be fluidized by passing a stream of gas upward through them with a certain velocity (Bryers and Kramer 1977, Wiley 1978). When the particles are fluidized, the bed has a hydrostatic head, and light objects float on its surface, while heavy ones sink. Individual particles undergo a high degree of mixing by moving about in the bed.

Particle size determines the rate of gas flow needed to effect fluidization. With a low rate of gas flow the bed of particles behaves as a porous medium, allowing the gas to pass through. As the rate of flow is increased, the point of incipient fluidization is reached where the pressure drop across the bed equals the weight per unit area of the bed. At this point, the particles start to float on the gas flow. Increasing the gas flow gives no further rise in the pressure drop across the bed. The extra flow passes through the bed as bubbles, and when 3-5 times the minimum fluidization velocity is reached, the bed resembles a violently boiling liquid. On fluidization the bed may expand from 1½ to 2 times its original static depth.

Fluidized beds have been used for many years in the petroleum and mining industries for catalytic and ore reactors (Keller 1975). More recently, they have been adapted to combustion systems. Because of the large particle surface area in the fluidized bed, rapid heat transfer occurs between gas and solids. As the fluidized bed has high thermal inertia, fluctuations in heat input are dampened. This permits combustion of wet and low-quality fuels that vary in heating value. The mineral olivine has been found to be a suitable bed material as it is inert to combustion temperatures up to 2000°. Bed material wears out by attrition and forms fines that are blown out of the system with the fluidizing gas flow.

Fluidized-bed burners may be used with existing boilers or water tubes can be inserted into the bed or placed in the wall of the burner. The hot combustion gases can also be used for direct heat drying applications (Bryers and Kramer 1977, Wiley 1978). A modified gas turbine cycle coupled to a fluidized bed burner has also been proposed. Such a system will fit into future mill energy needs by providing a higher ratio of electric power to steam power while

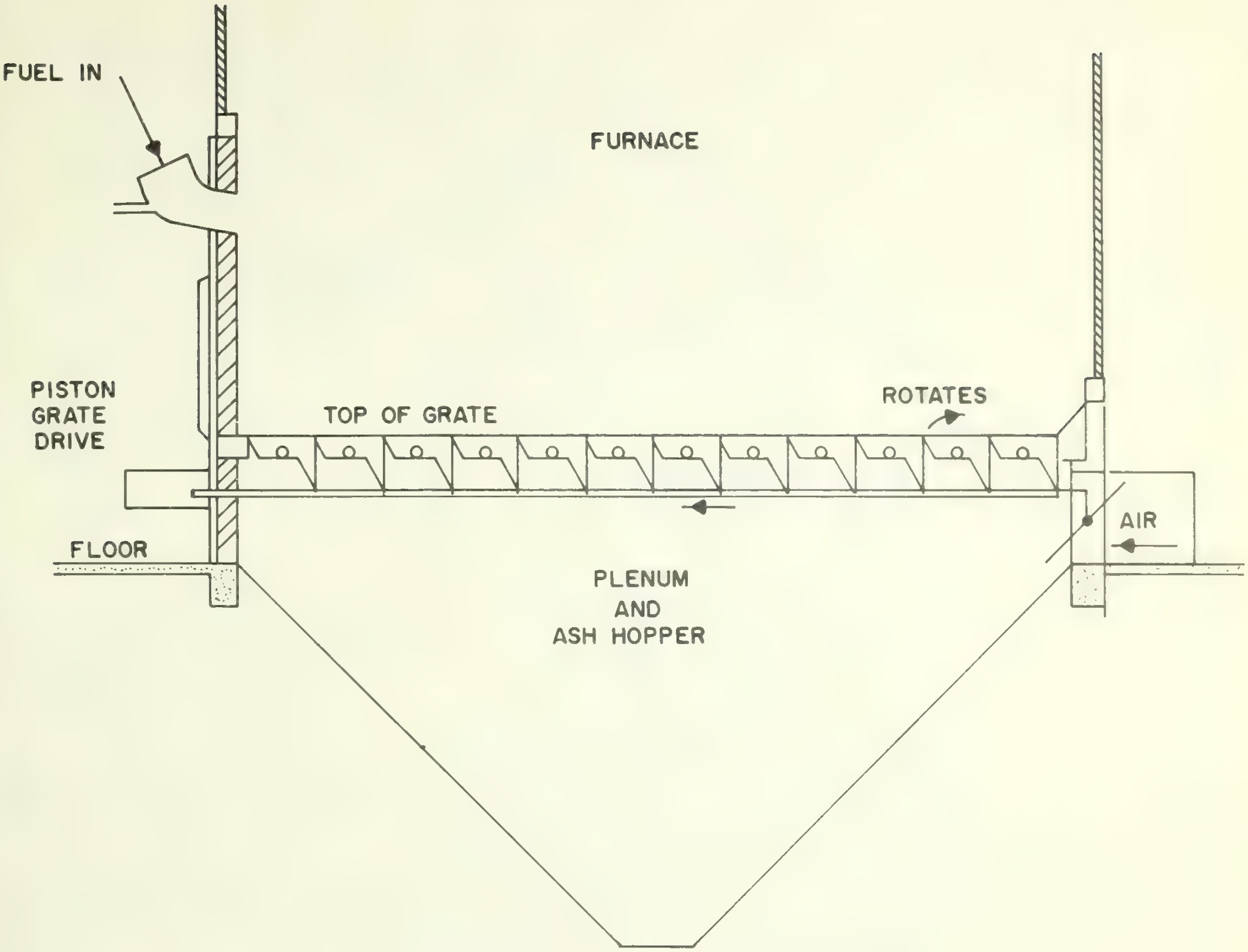

Figure 3-12.—*Dumping grate stoker. (Drawing after Fuller 1976.)*

utilizing a variety of low-grade fuels (Moody 1976).

In the fluidized-bed burner shown (fig. 3-17), the bed is preheated from 700 to 750°F with a nonfluidized airflow for startup. Then, a small amount of fuel spontaneously ignites as it is added to the bed. Once a flame is established, the bed is fluidized by increasing the airflow and then fuel feed is started. As combustion becomes self-sustaining, the temperature of the bed will rapidly rise into the operating range of 1,000 to 1,800°F. Preheat burners can then be turned off and no auxiliary fuel is required.

Fuel moisture contents can be up to 65 percent. Exhaust gas temperatures are normally up to 2,200°F and bed temperatures around 1,750°F. The largest units being constructed will handle 250 tons per day of hogged fuel and generate 55,000 lb of steam per hour. It is not expected that large units comparable to the spreader stokers will be built in the near future (DeArmond et al. 1975, Keller 1975).

Jasper-Koch Burner.—The Jasper-Koch burner (fig. 3-18) takes a new approach to suspension burning. The unit is designed to burn wet wood or bark efficiently in a small furnace that costs less than grate-type furnances of comparable capacity.

As we have said, bark or sawdust that is half water by weight burns very poorly and must be partially dried before combustion occurs. This drying can take place in a separate dryer before burning, in a pile on the floor of the furnace combustion chamber, or in an integral dryer that passes through the combustion zone. The Jasper-Koch burner works on the latter principle.

In the Jasper-Koch design, the combustion chamber is an annular space between two concentric vertical cylinders; particulate fuel burns in suspension in this chamber (fig. 3-19). In the commercial prototype, a stainless steel inner cylinder 29 inches in diameter with walls 1/4-inch thick houses a vertical downfeeding screw that introduces fuel into the bot-

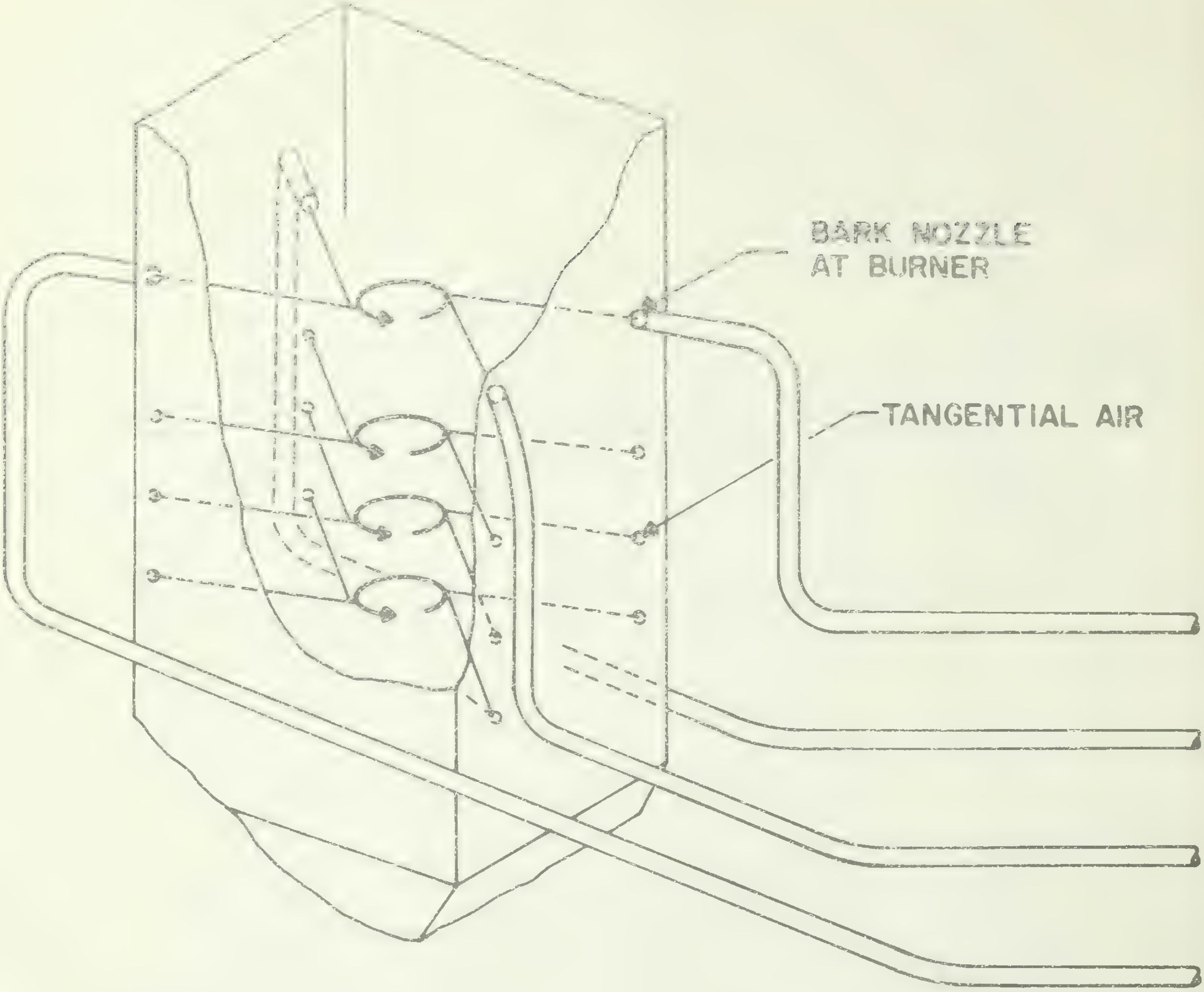

Figure 3-13.—*Schematic of a suspension firing system used in large boilers. (Drawing after Fernandes 1976.)*

tom of the chamber. The outer stainless steel cylinder that confines the upward-moving combustion gases is 49 inches in diameter and has walls 1/4-inch thick. The fuel is partially dried (nearly ovendried) in its 15-minute transit to the combustion zone.

Surrounding the outer cylinder, along the entire 7-foot-high burning zone, is a heat exchanger that preheats air to about 500°F and introduces it at high velocity (1,000-1,300 fpm) into the bottom of the burner. This air conveys fuel particles upward into the combustion zone, where the temperature is about 1,600°F. A 30 hp blower is required for the preheated air to assure proper airflow and velocity.

The burner has neither grate nor fuel bed. Combustion occurs throughout a zone in which particles are suspended in the air stream. The outer cylinder is flared at the top of the combustion zone. Since the inner cylinder has constant diameter, the flare increases flow area for upward-moving combustion gases slowing their velocity. This causes particulate matter (other than fine ash) to fall back into the burning zone for continuous recirculation until completely burned. Neither the laboratory model nor the commercial prototype formed slag since combustion temperatures do not exceed 1,800°F. Ash formed during combustion is discharged upwards along with hot combustion gases for later separation. The burner is equipped with a gas jet of one million Btu/hour capacity to facilitate startup.

The nonuniformity of fuel particle size is a problem for designers of wood burning furnaces. Most grate-type furnaces operate best with particles of pulp-chip size and cannot tolerate more than 50 percent sawdust or fines in the fuel mixture. Because

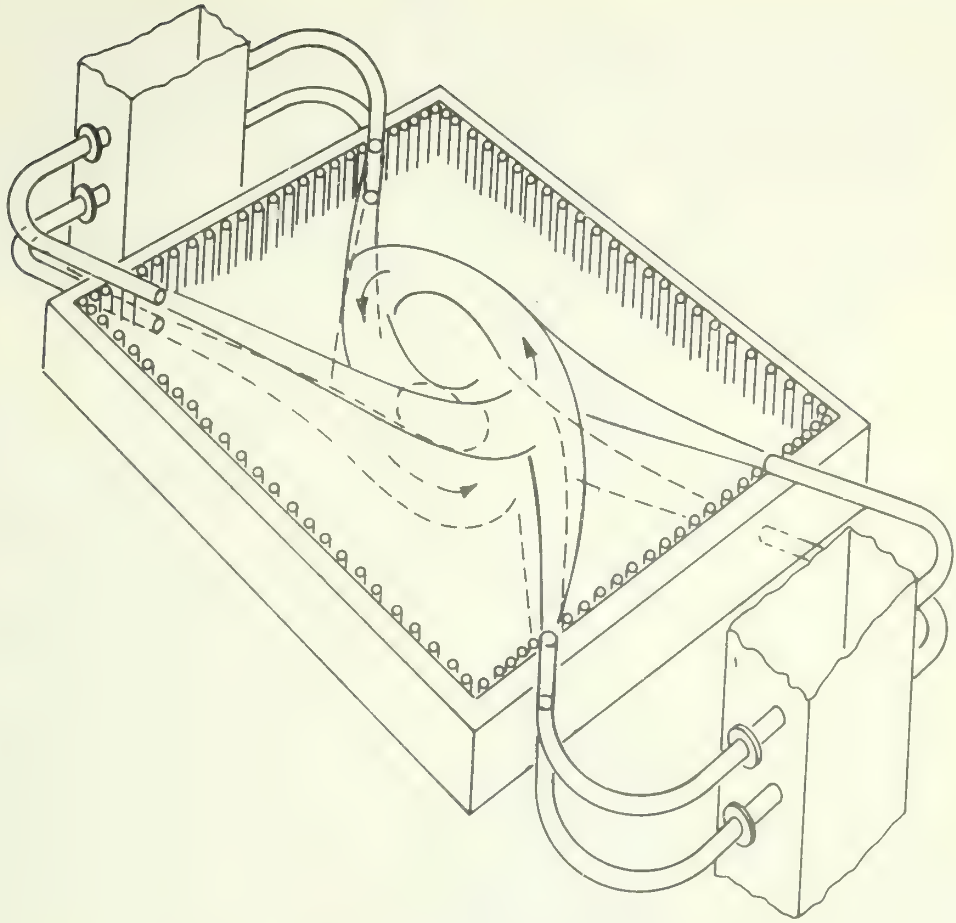

Figure 3-14.—*Tangential firing concept. (Drawing after Fernandes 1976.)*

wood particles can be hammermilled to smaller size, but cannot be increased in size (unless pelletized), the operators of grate-type furnaces have difficulty with an oversupply of fines and sawdust.

In the suspension burner, small particles are needed. Tests on the prototype have shown that the burner runs well with particles sized through the screen of a hammermill hog. Heat of combustion of the fuel was 8,500 Btu per ovendry pound. Ash contents ranged from 1 to 4 percent of dry weight, and moisture content as admitted to the infeed screw was 53 percent (wet basis).

3-3 Steam and Electrical Generation

Steam delivery from boilers can be expressed as kilo Btu's per hour, boiler horsepower, or pounds per hour (Miller 1976). *Kilo Btu* means 1,000 Btu and is a term commonly used by engineers.

Operators of small steam generating units sometimes express steam delivery in *boiler horsepower* (BoHP), a unit that bears no relationship to engine horsepower. Boiler horsepower was more commonly used in past decades when small steam plants were used to drive machinery. Boiler horsepower is the energy required for the evaporation of 34.5 lb of water per hour to saturated steam at 212°F at atmospheric pressure. The equivalent amount of heat energy in Btu's is 33,480 Btu/hr.

The amount of wood required to generate 1 BoHP can be calculated if boiler efficiency and fuel moisture content are known. The average green pine-site hardwood with 42 percent moisture content has an available heat of 4,540 Btu/lb (table 2-8). If we assume a boiler efficiency of 63 percent, then 11.7 lb per hour of green wood would be required to produce 1 BoHP:

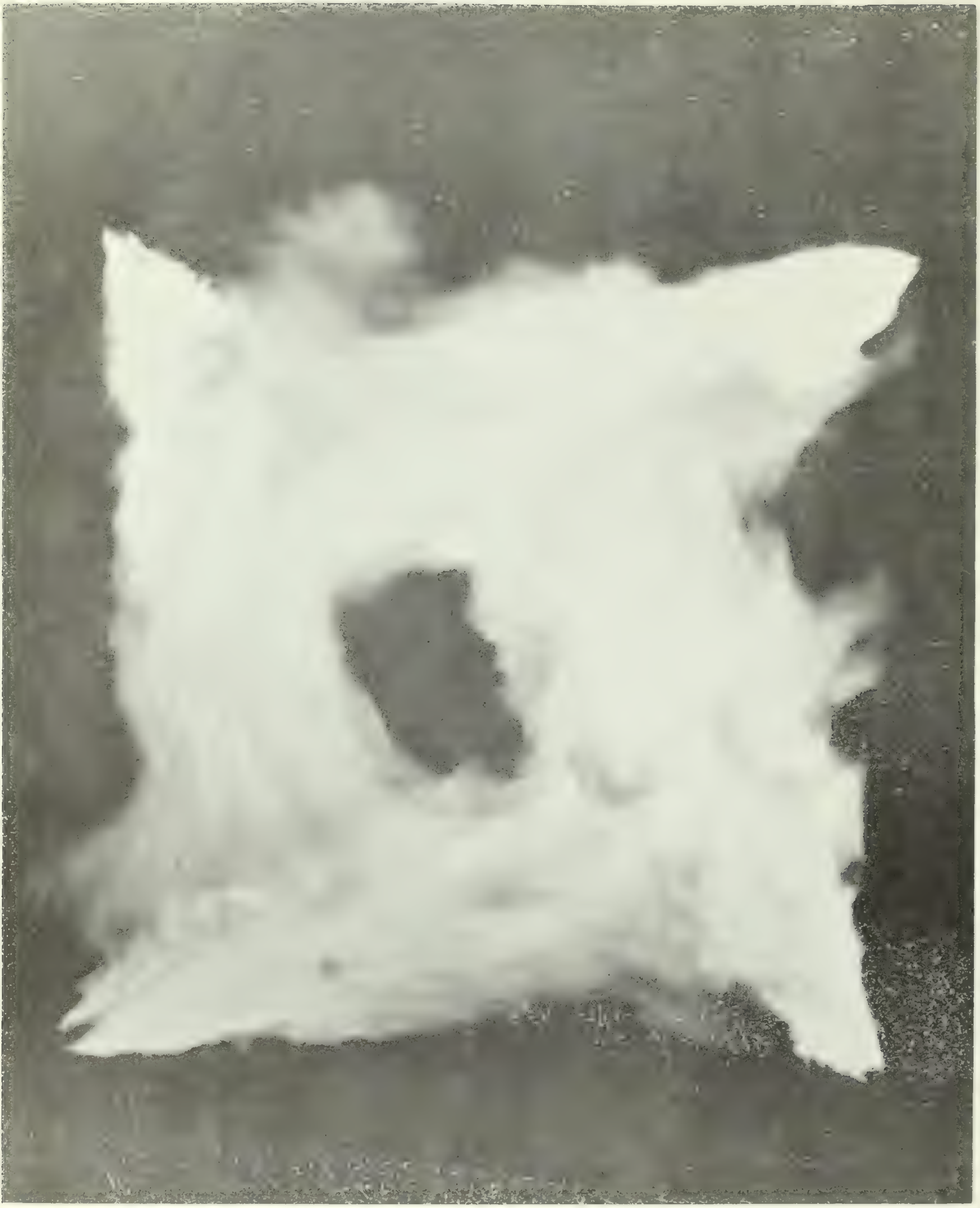

Figure 3-15.—*Photograph of fire circle produced by tangential firing inside a large boiler. (Photo courtesy of Combustion Engineering, Inc.)*

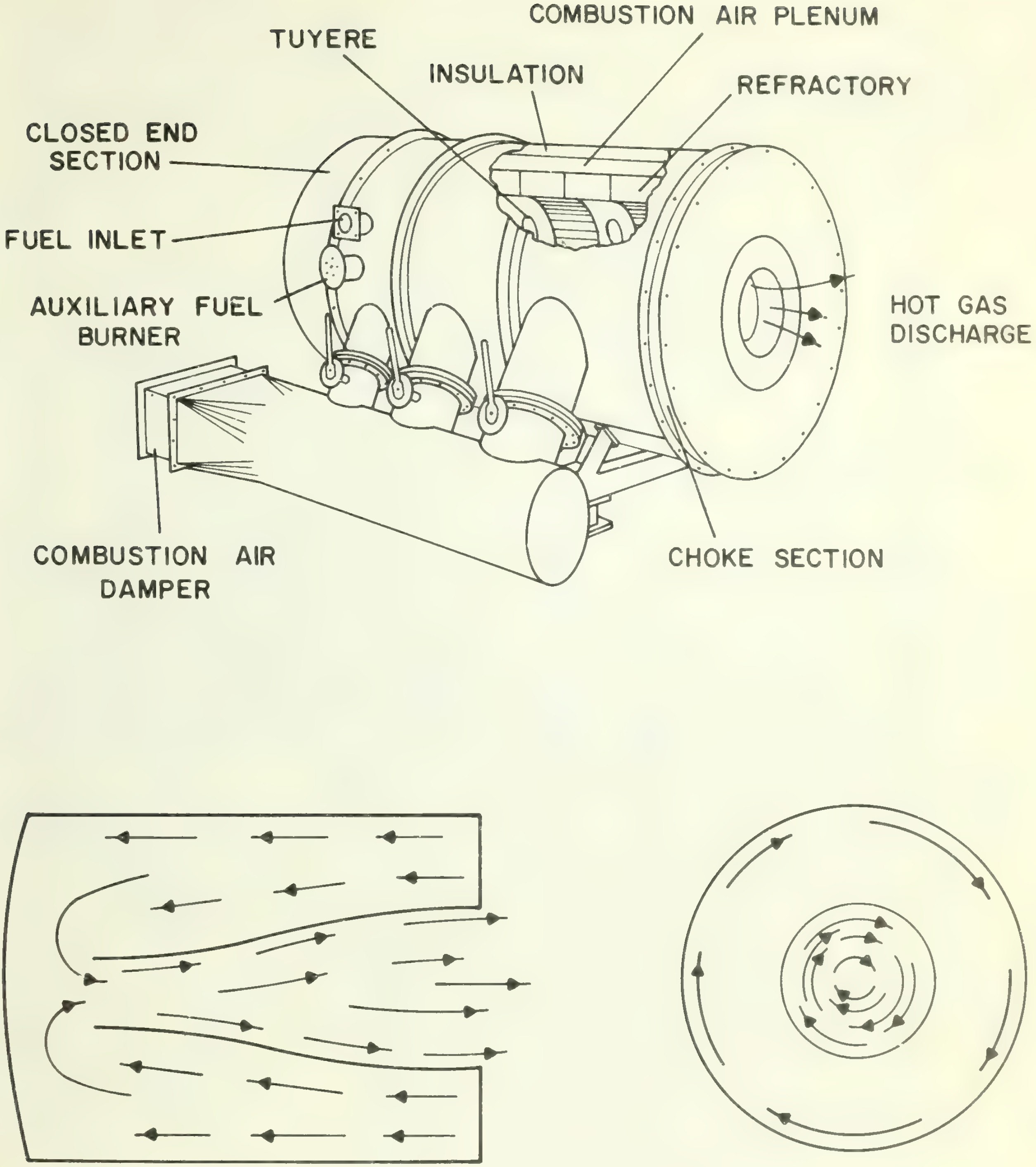

Figure 3-16.—*Cyclonic burner and airflow pattern in cyclonic burner. (Drawing from Energex Company.)*

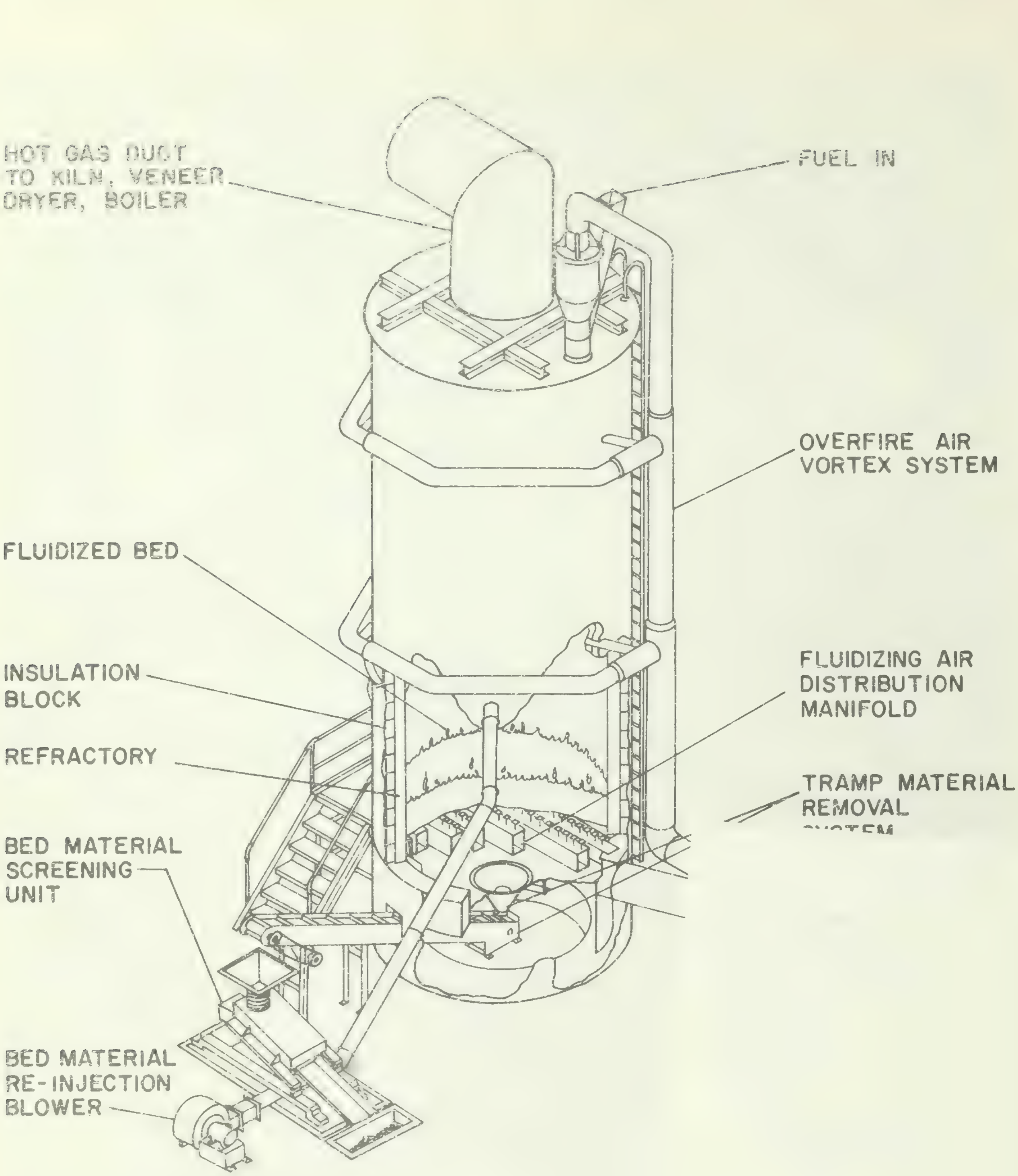
HOT GAS DUCT TO KILN, VENEER DRYER, BOILER
FUEL IN
OVERFIRE AIR VORTEX SYSTEM
FLUIDIZED BED
INSULATION BLOCK
FLUIDIZING AIR DISTRIBUTION MANIFOLD
REFRACTORY
TRAMP MATERIAL REMOVAL
BED MATERIAL SCREENING UNIT
BED MATERIAL RE-INJECTION BLOWER

Figure 3-17.—*Fluidized bed combustion unit. (Drawing from En*

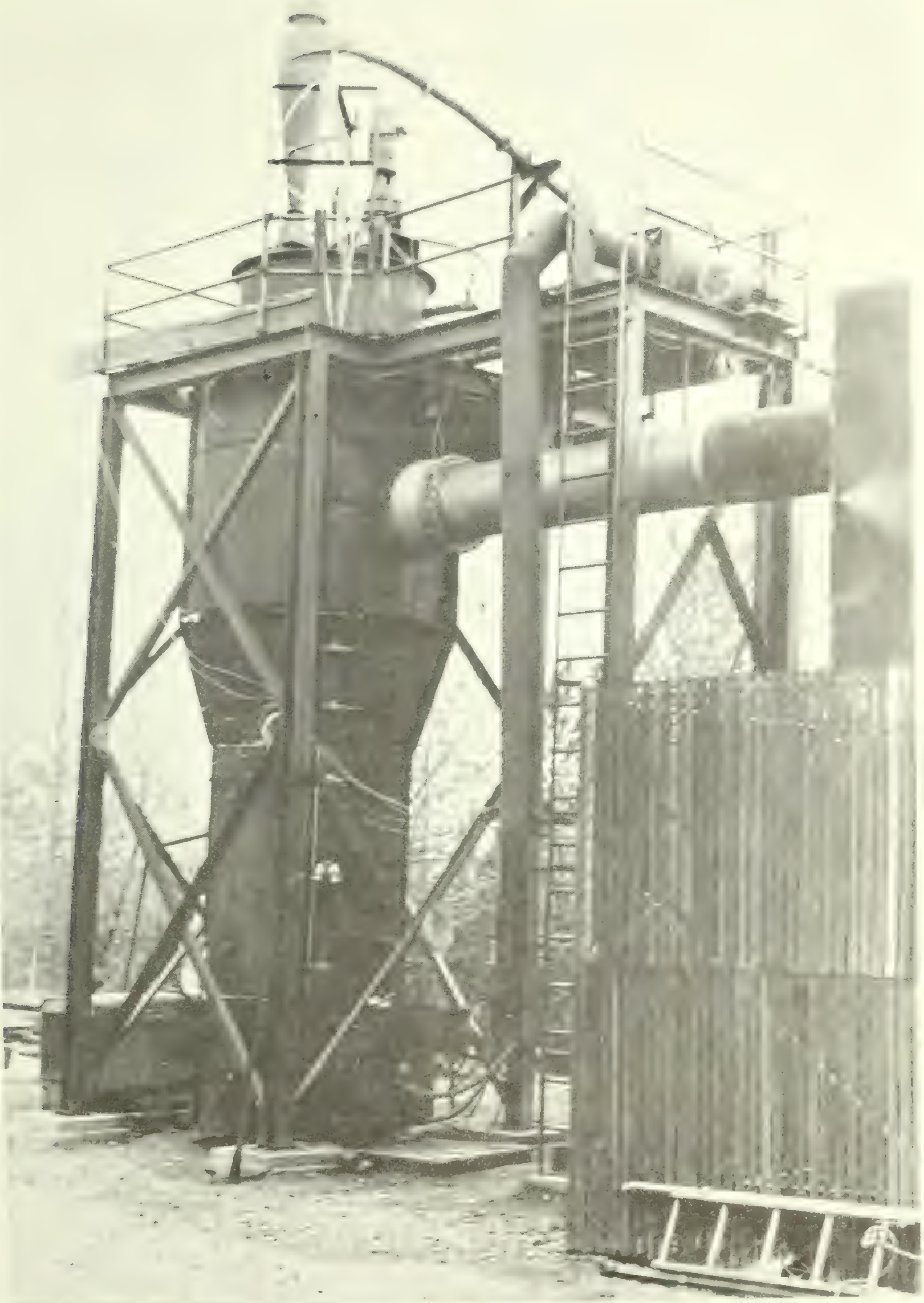

Figure 3-18.—*Photograph of the prototype of the Jasper-Koch burner*

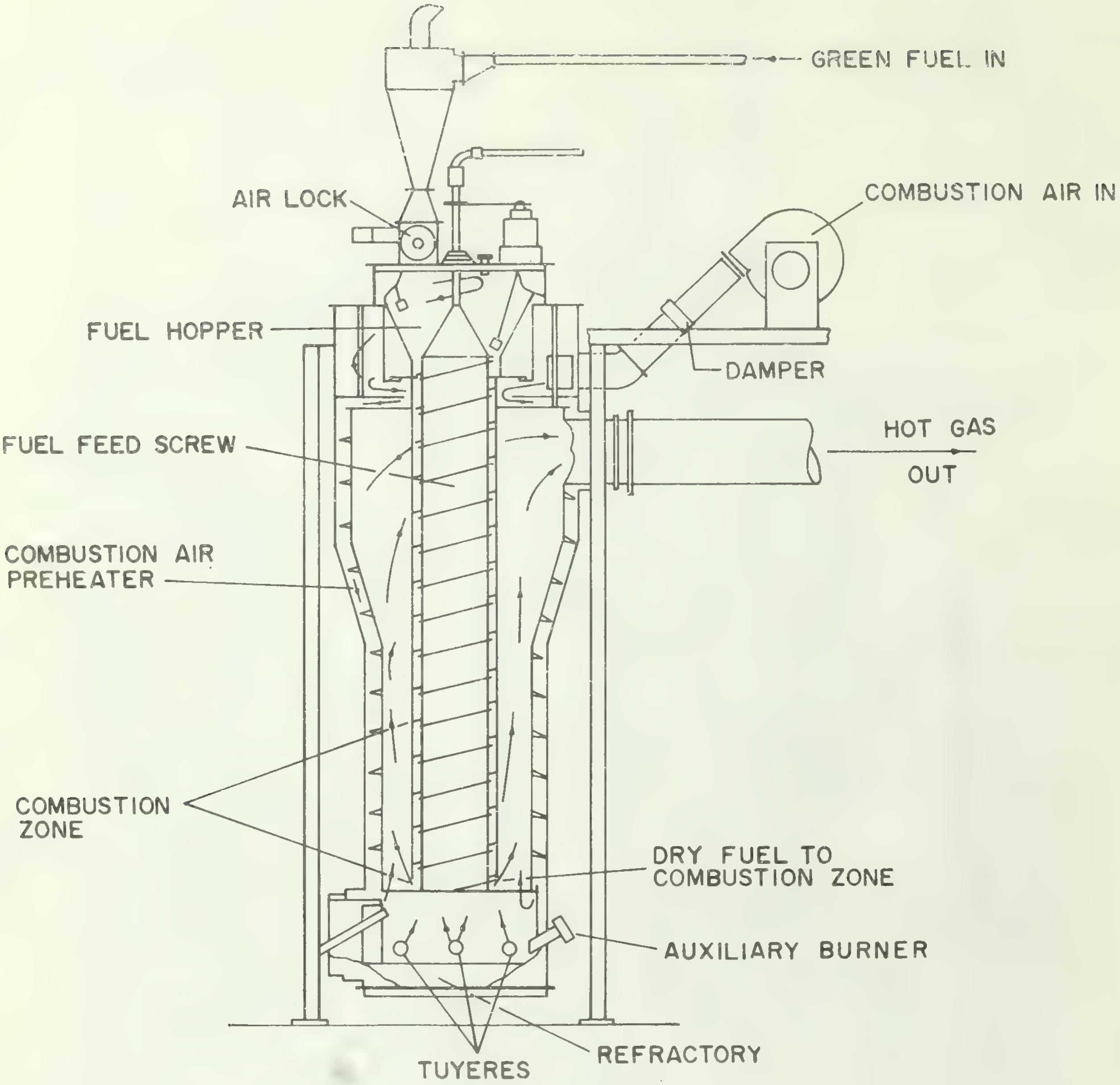

Figure 3-19.—*Cross sectional view of the prototype of the Jasper-Koch burner.*

$$1 \text{ BoHP} = \frac{33{,}480 \text{ Btu/hr}}{(\text{boiler efficiency})\ (\text{available heat of fuel, Btu/lb})}$$

$$\frac{33{,}480 \text{ Btu/hr}}{(0.63)\ (4{,}540 \text{ Btu/lb})} = 11.7 \text{ lb/hr}$$

Today, in the forest products industry the most common expression of steam delivery is number of pounds of steam delivered per hour *(PPH).* The unit is not an absolute measurement as steam at different pressures and temperatures will have different amounts of energy. For example, steam at 165 psi absolute and 550°F contains heat energy of 1,118 Btu/lb more than feed water at 212°F. Under such a system, the amount of green pine-site hardwood (average available heat, 4,540 Btu/lb) required to deliver 50,000 lb of steam per hour with a boiler efficiency of 63 percent is equal to (50,000 lb steam/hr) (1,118 Btu/lb steam) ÷ (0.63) (4,540 Btu/lb wood), or 19,544 lb of wood per hour.

Overall *boiler efficiency* is expressed as energy output divided by energy input:

$$\text{Percent efficiency} = \frac{\text{output}}{\text{input}} \times 100 \qquad (3\text{-}8)$$

This energy input equals the dry weight of fuel multiplied by the higher heating value of the fuel:

$$\text{Input} = m_f \times q_h \qquad (3\text{-}9)$$

m_f = dry weight of fuel burned, lb/hr
q_h = higher heating value of fuel, Btu/lb

The output equals the steam generated multiplied by the difference in heat contents of the feed water and steam leaving the boiler:

$$\text{Output} = m_g (h_1 - h_2) \qquad (3\text{-}10)$$

m_g = steam generated, lb/hr
h_1 = heat content of steam leaving boiler, Btu/lb
h_2 = heat content of feed water, Btu/lb

The instrumentation and procedures required to measure efficiency can become complicated. However, the process of calculating overall efficiency can be greatly simplified by assuming that everything going into the furnace comes out as mass or energy (Hughes 1976). Then, boiler output does not have to be measured and overall boiler efficiency can be expressed as:

$$\text{Percent efficiency} = \frac{\text{input} - \text{losses}}{\text{input}} \times 100 \qquad (3\text{-}11)$$

Corder (1973) lists the sources of boiler heat loss as follows:

(a) moisture in fuel
(b) moisture formed from hydrogen in fuel
(c) dry stack gas loss
(d) incomplete combustion, radiation, and unaccounted sources.

In equation 3-11 the sum of (a) through (d) equals losses. Losses due to (a) through (c) can be readily calculated if the moisture content, ultimate analysis (table 2-6), and higher heating value (table 2-5) for the fuel are known. The ultimate analysis is required to calculate the amount of air needed for combustion. Corder (1973) estimates that item (d) accounts for a 4 percent heat loss, but the loss could be substantially greater in poorly insulated boilers.

A procedure outlined by Wiley (1976) was used to calculate overall boiler efficiency for pine-site hardwoods at various moisture contents (table 3-5). It was assumed that the furnace used 40 percent excess combustion air and that the stack gas temperature was 500°F (Corder 1973), values that might be expected for efficient burning of hogged fuel. The overall efficiency for green stemwood of average moisture content (42 percent wet basis, table 3-5) is 63 percent.

Table 3-5.—*Overall boiler efficiency versus pine-site hardwood moisture content*[1]

Heat loss from	Moisture content[2]			
	10%	25%	42%	50%
	Percent loss			
Moisture in wood[3]	1	5	12	16
Moisture from hydrogen in fuel[3]	9	9	9	9
Dry stack gases[3]	12	12	12	12
Incomplete combustion, radiation and unaccounted[4]	4	4	4	4
Total heat loss	26	30	37	41
Overall boiler efficiency	74%	70%	63%	59%

[1] Boiler operating with 40% excess air and stack temperature of 500°F.

[2] Wet basis.

[3] Calculated by Wiley's method (1976); average stemwood value of 7,827 Btu/lb used (Table 2-5).

[4] Estimated (Corder 1973).

High fuel moisture content is the most important factor in loss of boiler efficiency. The loss is a function of both the amount of moisture in the fuel and the stack gas temperature. Heat is lost both in vaporizing the water and in raising the temperature of the steam to that of the stack gases. At 50 percent moisture content, 16 percent of the fuel energy is lost up the stack (table 3-5). If the moisture content can be reduced to 10 percent, less than 1 percent of the fuel energy is lost and overall efficiency is 74 percent.

Evaporation of moisture formed from the combustion of hydrogen in wood also causes loss in boiler efficiency. One lb of dry wood with 6.4 percent H will produce 0.58 lb of water on combustion (equation 3-2). This results in a 9 percent loss in boiler efficiency.

Dry stack gas heat loss depends on both the amount of excess air and stack temperature. As excess air and stack gas temperature increase, heat loss increases (Corder 1973). When pine-site hardwoods are used as fuel, the loss is estimated at 12 percent with 40 percent excess air and 500°F stack gases. After the gases have passed through the steam-generating heat exchangers, heat can be salvaged from the gases by passing them through a second set of heat exchangers called economizers. Economizers can be used to predry incoming fuel and to preheat incoming combustion air.

The overall conversion efficiency for conventional steam generation of electricity from wood is about 25 percent (Benemann 1978, Love and Overend 1978). This estimate includes boiler efficiency, steam cycle efficiency, and auxiliary power requirements, all of which can vary. The amount of pine-site hardwood required to generate a kilowatt-hour (Kwhr) can be calculated as follows. For green pine-site hardwood of 42 percent moisture content (wet basis), the available heat is 4,540 Btu/lb (table 2-8). As 1 Kwhr = 3,412 Btu,

$$1 \text{ Kwhr} = \frac{3{,}412 \text{ Btu}}{4{,}540 \text{ Btu/lb } (0.25)} = 3 \text{ lb green pine-site hardwood}$$

The amount of wood required to fuel electrical generating plants, assuming 25 percent conversion efficiency is as follows:

Electrical generating plant size	Amount of green pine-site hardwood required for fuel
5 MW	7.5 ton/hr
25 MW	37.5 ton/hr
250 MW	375 ton/hr
500 MW	750 ton/hr

Co-generation of steam and electricity from a boiler plant is becoming an accepted practice in the forest products industry (Pingrey and Waggoner 1978). It is not a new process, but interest in it has been renewed in recent years. In the 1920's, co-generation was common on the West Coast as it was the only way to obtain electricity for mill operations. As electricity from utilities became available, the electrical generation systems were shut down.

One method of co-generation that is becoming common is first to pass steam through a back pressure-type turbo-generator to produce electricity while using the exhaust from the turbo-generator for process steam in the mill. In this way the steam is used twice. Since there is no cooling water or cooling tower, the turbo-generator takes only the amount of energy out of the steam necessary to generate electricity, and the remaining energy is in the process steam. Exhaust pressures commonly vary between 25 psig to 200 psig depending on the usage.

Pingrey and Waggoner (1978) have estimated that in the United States the overall generating capacity of electrical generating plants using wood and wood derived fuels is about 4,500 MW (table 3-6). Many of the plants, however, use fossil fuels at the same time they are burning wood and wood derived fuels. For instance, it is estimated that on an annual basis, the pulp and paper industry burns 54 percent fossil fuels to generate electricity, while wood residues and pulping liquors supply the remaining 46 percent. On the other hand, solid wood products mills are estimated to use 98 percent wood fuel and only 2 percent fossil fuel.

Table 3-6.—*Estimated generating capabilities of electric generating plants in the United States that use wood and wood derived fuels*[1]

Producers	Generation capability
Pulp and paper mills	3,600 MW
Solid wood products	800 MW
Utilities	60 MW
Other[2]	40 MW
Total	4,500 MW

[1] Data from Pingrey and Waggoner (1978).

[2] Miscellaneous users of small wood fired plants which included a rubber plant, sugar mills, and a resort.

But outside the forest products industry, few wood-fueled electrical utilities are in operation. They are located in Eugene, Oregon; Libby, Montana; and Burlington, Vermont.

The Eugene utility has been using hogged fuel since the 1940's to generate electricity. The steam generated not only is used to run turbines, but is distributed to the central part of the city, where it is used to heat businesses and homes and provides process steam to plants such as laundries (Anonymous 1977).

3-4 Domestic Stoves and Fireplaces

High oil, natural gas, and electricity prices have renewed the public's interest in home and shop space heating with wood. Wood is readily available and improvements in woodstove design and devices to make stoves and fireplaces more efficient have come about with the renewed interest in wood burning (Shelton and Shapiro 1976, and Lew[6]).

Firewood for personal use is usually available free from both State and National Forests. Owners of small woodlots also sell culled hardwoods as domestic firewood. The pine-site hardwoods make excellent firewood for home use. They are more dense and burn less vigorously with a longer lasting fire than resinous softwoods. Oak is probably best as it gives the most uniform flames while producing hot and long lasting coals (U.S. Forest Service 1974).

Fireplaces generally are not very efficient (minus 5 to 10 percent) because much heat is lost up the chimney (Shelton and Shapiro 1976). One device to make fireplaces more efficient is a hollow grate through which air can be circulated. Glass doors with controlled air intakes can be placed on a fireplace to reduce the amount of air entering from the room. With reduced airflow the fire burns more slowly and less heat is lost up the chimney. In new fireplace installations, heat-circulating fire boxes can be incorporated behind the hearth.

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[6] V. Lew, "Wood Burning Stoves," a staff report to the Fuels Office, Alternatives Division, California Energy Commission, June 14, 1978, Sacramento, California.

Wood burning stoves are considerably more efficient than fireplaces; efficiencies can range from 25 to about 70 percent[6] Stove design is generally based on controlling combustion air and enhancing heat transfer to the room. Combustion air can be controlled with secondary air inlets, airtightness, and different airflow patterns through the stove. Secondary air, which is often provided in a secondary combustion chamber, is used to combust completely volatile gases produced from the burning wood. In airtight stoves, control over the amount of combustion air entering is accomplished by welding or cementing the stove sections together. Air leaks in non airtight stoves occur through cracks around the door and at other places where parts are joined. These leaks cause lost efficiency because the air entering is not involved in combustion and takes heat out through the chimney. The control over airflow gives airtight stoves longer burning times and causes them to use 25 to 50 percent less wood.

Many different wood stoves are on the market today. Most can be broadly categorized on the basis of the flow pattern of air through the stove (Shelton and Shapiro 1976). The five basic patterns are: up, diagonal, across, down, and "S" (figure 3-20).

In the updraft pattern the combustion air enters below the burning wood and travels up through the grate. Secondary air may be necessary above the wood for complete combustion of volatiles. Examples of updraft stoves include the pot-bellied stoves and the Shenandoah.

The diagonal flow pattern is found in the simple box stove. Air enters the stove at the bottom front of the combustion zone and travels diagonally through the burning wood, exiting at the top back corner. Secondary air inlets again may be supplied above the burning wood for more efficient combustion. Examples of this flow pattern include the Ashley 25HF, Fisher and drum stoves (Shelton and Shapiro 1976).

In the across pattern, air enters the stove at the bottom front but moves horizontally across the wood to exit at the lower back. Considerable turbulence occurs above the burning wood and volatile gases are forced through the hot coals or flames at the back of the combustion chamber. Secondary air is usually provided at this point. Stoves with both the across and downdraft flow patterns usually require a bypass damper to prevent smoke from entering the room when the stove door is opened. Many stoves using the across flow are airtight and have large fuel capacities so that refueling is not necessary for long periods (Shelton and Shapiro 1976).

In downdraft stoves, air enters the stove above the grate and passed down through the grate along with emerging volatiles produced from the burning wood. Secondary air can be provided at a number of points, often at the bottom of a baffle plate at the back of the stove. Combustion is then completed in a secondary chamber. This design is one of the better ones for efficient burning of wood. Downdraft stoves are usually airtight and can also operate for long periods between fueling (Shelton and Shapiro 1976).

Wood usually rests directly on the firebox floor in the S-flow stoves. A horizontal baffle extends from the back of the stove and prevents air flow and volatile gases from leaving the combustion area directly. The S-flow provides extra turbulence and burning time for the volatiles, and the baffle also helps to increase heat transfer from the hot gases to the outside of the stove. Wood tends to burn from the front of the stove to the back. These stoves are noted for a steadiness of heat output and high efficiency. Common examples of this type of stove are the Norwegian Jøtul, Lange, and Ram woodstoves[6]

The economics of home heating are attractive if an efficient wood stove is used. Lew[6] has estimated that one cord of red oak (21 million Btu's per cord) burned in an airtight stove (50 percent efficiency) will yield heat equivalent to the use of 1.1 tons of coal, 115 gallons of number 2 fuel oil, 14,000 cubic feet of natural gas, or 3,074 kilowatt hours (Kwhr) of electricity. If a person heats with electricity and pays about 4¢ per Kwhr, the equivalent electricity cost would be $123. In the case of box stoves or Franklin fireplaces (30 percent efficiency), the heat realized would be equivalent to 1,848 Kwhr or $74. In a fireplace with 10 percent efficiency, the heat realized would be equivalent to only 616 Kwhr, or about $25 per cord. It is thus apparent that savings will depend greatly on the efficiency of the burning system.

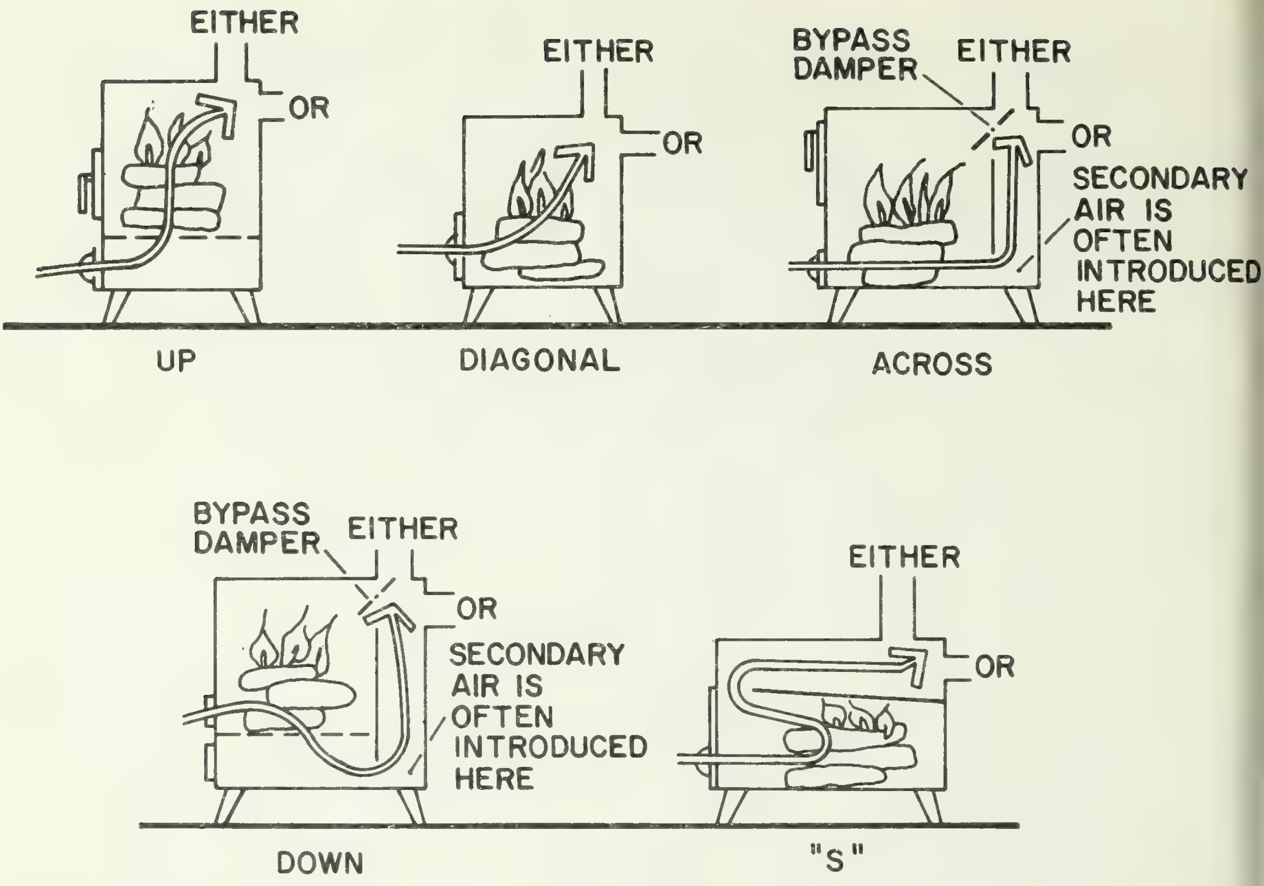

Figure 3-20.—*The five basic air flow patterns found in domestic stoves. Stoves with both the across- and down-draft flow patterns usually require a bypass damper to prevent smoke from entering the room when the stove door is opened. (Drawing after Lew[6])*

CHAPTER 4

Gasification

Gasification is thermal decomposition of organic material in the presence of controlled and limited amounts of air or oxygen to produce a combustible mixture of gases, often referred to as producer gas. When air is used, the producer gas contains mostly hydrogen, carbon monoxide, and nitrogen. Lesser amounts of carbon dioxide, methane, and hydrocarbons are formed. The mixture is generally referred to as a *low Btu gas* (table 4-1). Heating values range from 100 to about 200 Btu/sdcf (standard dry cubic foot) (Levelton and O'Connor 1978, California State Energy Commission[7]).

When oxygen is used for gasification *medium Btu gas*, with heating values as high as 350 Btu/sdcf, is produced (Bliss and Blake 1977). Nitrogen dilution is eliminated so that the two major components of medium Btu gas are hydrogen and carbon monoxide. Lesser amounts of carbon dioxide, methane, and hydrocarbons are also produced (table 4-1).

The exact chemical composition of either low or medium Btu gas depends on variables that include gasification temperature, pressure, time, and presence of a catalyst (Love and Overend 1978). In the

Table 4-1.—*Typical composition for low and medium Btu gases produced on gasification of biomass*[1] [2]

Constituent	Low Btu gas	Medium Btu gas
	Percent	
Carbon monoxide (CO)	20	40
Hydrogen (H_2)	15	30
Carbon dioxide (CO_2)	10	20
Hydrocarbons (CH_x)	5	10
Nitrogen (N_2)	60	–

[1] Data from Benemann (1978).

[2] Composition varies.

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[7] California State Energy Commission, "Commercial Biomass Gasifier at State Central Heating and Cooling Plant," Feasibility Study prepared by Fuels Office, Alternatives Division, April 1978, 63 p.

crude state, both low and medium Btu gas contain high percentages of moisture which originates from the partial oxidation process and from moisture in the fuel. However, the moisture can be readily removed (Bliss and Blake 1977).

The basic processes in gasification are similar to those in combustion except that complete oxidation of carbon to carbon dioxide is avoided. Only sufficient air or oxygen is provided to the gasifier bed for (1) gasification of the carbon char by partial oxidation to carbon monoxide and (2) for generation of enough heat to support drying and pyrolysis of the fuel (Eggen and Kraatz 1976). Drying and pyrolysis of the fuel occur much as they do in combustion except the volatile gases produced are not oxidized. In pyrolysis, water vapor, carbon monoxide, and carbon dioxide are formed first. Then, more extensive decomposition gives tars which finally yield hydrogen and hydrocarbons leaving only a carbon char. The carbon char is partially oxidized to carbon monoxide by oxygen, water, or carbon dioxide. The carbon dioxide is then reduced to carbon monoxide. While the addition of air or oxygen to the fuel bed is necessary to sustain this complex oxidation-reduction scheme, no air or oxygen can be allowed to mix with the gases produced as they would readily combust.

Researchers are investigating the use of catalysts in gasification of wood (Feldman 1978, Walkup et al. 1978). A primary reason for catalyzing gasification would be to lower gasification temperature and to improve reactivity. The best catalysts found so far are calcium oxide and wood ash. Catalysis may also be used to selectively form one product. If such a catalysis system can be developed, gases that are predominantly methane, hydrogen, or carbon monoxide or optimum mixtures for a specific purpose might be produced. These products would be of much higher value than producer gas and would make gasification a more competitive conversion process.

Gasification is not new; coal was gasified in the late nineteenth century.[7] Early gasification units operated by blowing air up through the fuel bed and allowing gases to exit the top (updraft operation). The producer gas was used to fire boilers and furnaces.

After cooling and cleaning, producer gas has been used to fuel internal combustion engines. In fact, about 600 Crossley gas plants were constructed for that purpose between 1912 and 1940 (fig. 4-1, Levelton and O'Connor 1978). Reportedly some are still in working order.

Portable gasification units were developed during the 1940's.[7] About 700,000 vehicles were adapted to use producer gas in Europe during World War II. Coal, coke, and charcoal were commonly gasified; wood and crop residues had limited use. Although development of portable gasifiers mostly ceased after World War II, Swedish researchers produced a successful wood-fueled downdraft gasifier for use on agricultural vehicles.

While not a completely proven technology in all applications, wood gasification offers wide versatility (fig. 4-2). In North America, many types of wood gasifiers are in various stages of development (Levelton and O'Connor 1978). In general, wood gasifiers are smaller than the coal gasification units now under development and would be suitable primarily for smaller scale applications. Capacities of wood gasifiers are about 10 million Btu per hour or less.

4-1 Energy Production

On-Site Combustion of Producer Gas.—Most of the gasifiers under development are air blown and produce a low Btu gas suitable to be burned on site so that the immediate (sensible) heat of the gas can be utilized (Love and Overend 1978). Such on-site utilization is best for low Btu gas since the gas cannot be stored effectively, and its low Btu content makes transport economically unattractive. After modification of burner nozzles, low Btu gas can be burned in standard natural gas and oil furnaces.

Such gasifier systems would have advantages over solid-wood fueled furnaces. Ash and carbon residues would remain in the gasifier; the furnace would be subjected only to producer gas, a relatively clean fuel. While some tars, oils, and particulates may be carried over with the producer gas, in most cases no pollution controls will be needed on the furnace.[8]

A portable gasifier developed by the University of California was successfully tested using wood as a fuel at the California State printing plant where the low Btu producer gas was burned in one of the plant's boilers (fig. 4-3, table 4-2). A feasibility analysis indicated that no major technical barrier exists to commercialization of gasifiers that produce low Btu gas for furnace boiler fuel.[7] Emissions were within acceptable standards. The costs of using the gasifier system over 20 years would be competitive with the cost of using natural gas (in California) assuming price increases at the rate of inflation.

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[8] G. D. Voss and V. A. Gauger. Gasification of wood residues. Paper presented at the For. Prod. Res. Soc. Annu. Meet. (Denver, Colo. July 1977). 13 p.

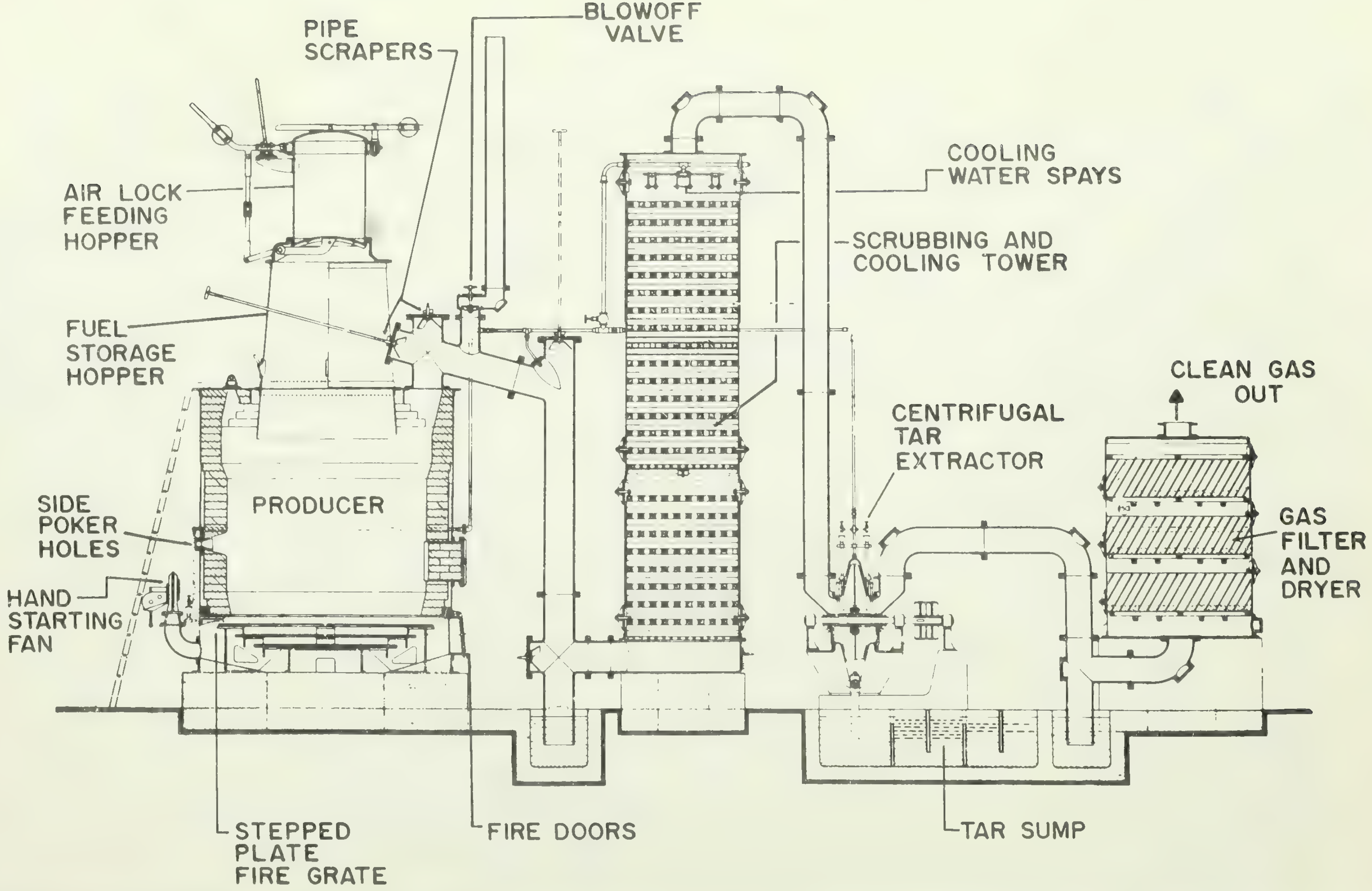

Figure 4-1. – *Original Crossley gas plant. (Drawing after Levelton and O'Connor 1978.)*

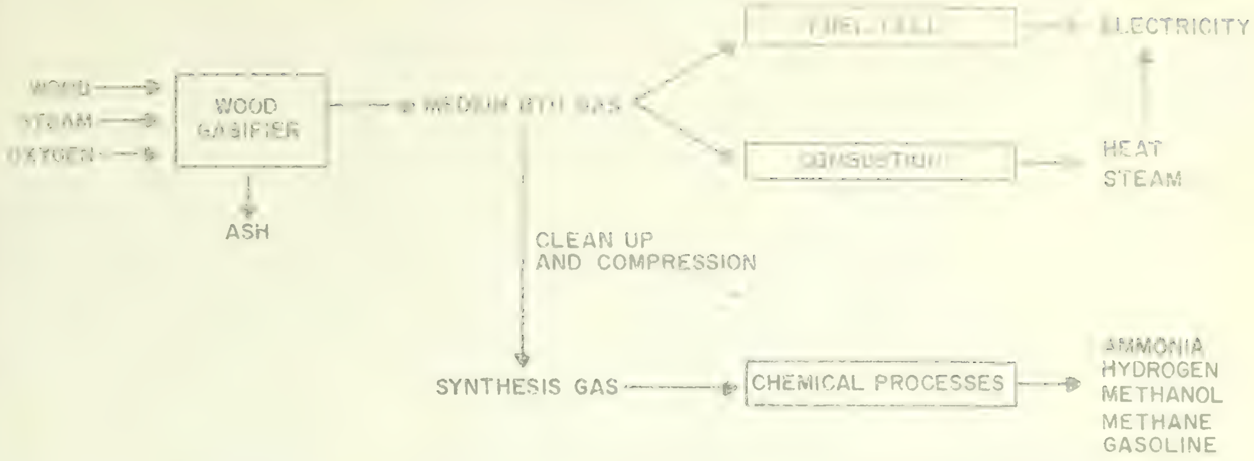

Figure 4-2.—*Gasification scheme for the production of energy, chemicals, and synthetic fuels from wood.*

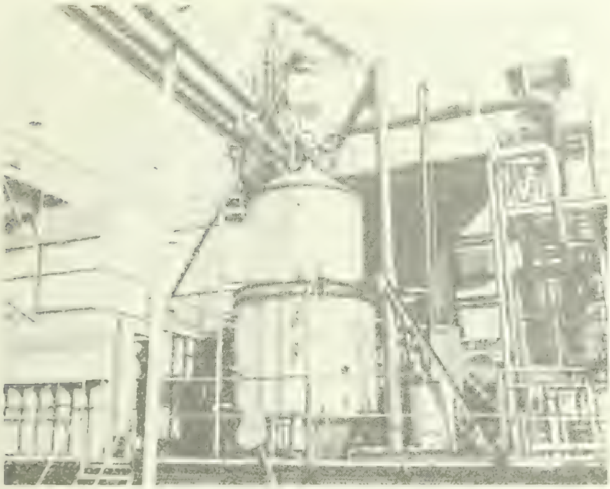

Figure 4-3.—***Downdraft gasifier developed by the University of California. (Photo courtesy of Robert Hodam, California State Energy Commission.)***

Table 4-2.—*Input and output for one hour of prototype gasifier operation*[1]

Input	Output
.75 ton of wood	10 million Btu of gas
1 gallon of gasoline	100 lb of char
5 Kw of electricity	1 quart of tar
	SO_x — negligible
	NO_x — 129 ppm
	particulates — 0.8 grams per standard cubic foot

[1] Data from California State Energy Commission (1978).

Fuel Cells.—The generation of electricity by *fuel cells* that use producer gas from wood is an unproven process but potentially a viable one (Hodam 1978, Eggen and Kraatz 1976). Fuel cells use hydrogen and oxygen (from air) to convert stored chemicai energy directly to electrical energy (fig. 4-4).

$$2H_2 + O_2 \xrightarrow{\text{Fuel Cell}} 2H_2O + \text{heat} + \text{electrical power} \quad (4\text{-}1)$$

The concept is not new. Fuel cells have provided power for moon landings and on a demonstration basis, electricity to apartments, commercial establishments, and small industrial buildings. It is expected that electrical generation from coupling wood gasifiers with fuel cells will be significantly more efficient than using turbines or diesel engines (Hodam 1978).

Fuel cells can produce electricity at 38 to 40 percent efficiency, a rate about equal to the best combustion power plant. It is expected that by 1985 fuel cell efficiency may be 50 to 55 percent. Fuel cell emissions are well within environmental limits (Energy Research and Development Administration 1976).

4-2 Chemicals and Fuels Production

Synthesis gas (hydrogen and carbon monoxide) can be used to produce several important chemicals and fuels (Wender in press). Methane, hydrogen, ammonia, methanol, ethylene glycol, and gasoline can be made directly from synthesis gas. Additionally, a high octane gasoline can be produced from methanol in a one-step process.

Medium Btu gas from wood gasification should be well suited for use as synthesis gas because of its high hydrogen and carbon monoxide content. On the other hand, low Btu gas would not be so well suited since large amounts of nitrogen would have to be removed to convert it to synthesis gas. An exception might be in ammonia production.

Hydrogen, Methane, Ammonia, and Methanol.—*Hydrogen* can be produced by the *water shift* [illegible] *tion* (Wender in press). Hydrogen already in the

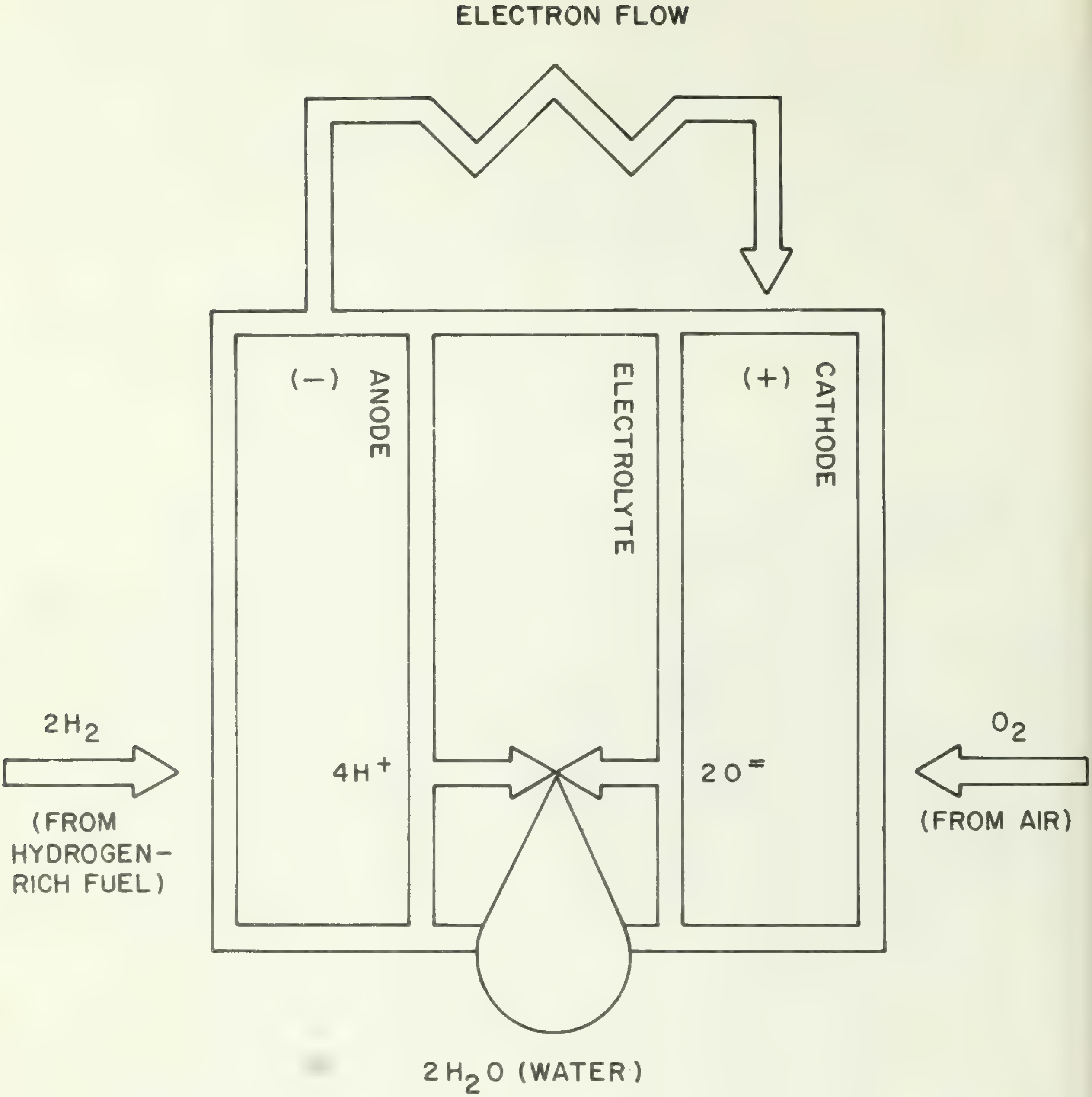

Figure 4-4.—*The basic principles of fuel cell operation (Energy Research and Development Administration 1976). The fuel cell consists of an anode, cathode, and electrolyte much as in a battery. Hydrogen rich fuel is fed down the anode side of the cell. Here the hydrogen leaves its electrons giving the anode a negative charge. Air enters the fuel cell on the cathode side. Here oxygen accepts electrons from the cell giving the cathode a positive charge. Electrical power is generated by the flow of electrons from the anode to the cathode. Hydrogen ions formed at the anode and oxygen ions formed at the cathode migrate through the electrolyte to combine and form water. Heat is also liberated in the process. The overall simplified process is shown in equation 4-1. (Drawing from Department of Energy.)*

synthesis gas remains unchanged, but added water reacts at high temperature with carbon monoxide and a catalyst to yield hydrogen.

$$CO + H_2O \xrightarrow{\text{catalyst}} CO_2 + H_2 \qquad (4\text{-}2)$$
$$\Delta H = -9.84 \text{ kcal}$$

Carbon dioxide formed can be removed from the gas stream to give pure hydrogen gas. The reaction is also used to obtain hydrogen to carbon monoxide ratios appropriate for certain syntheses. Methanol production requires $2H_2{:}1CO$, while methane requires $3H_2{:}1CO$.

Hydrogen can also be used as a fuel, although its general use as such may be in the more distant future. However, hydrogen holds much promise as it is an environmentally clean fuel; combustion yields only water and heat energy. Therefore, one might expect to see increased use of hydrogen as a transportation fuel, especially for mass transit in areas with air pollution problems. A promising new technology is in the development of metal hydrides for the safe storage, shipping, and use of hydrogen as a fuel.

Methane (CH_4) can be produced by the *methanation reaction* shown below:

$$3H_2 + CO \xrightarrow{\text{catalyst}} CH_4 + H_2O \qquad (4\text{-}3)$$
$$\Delta H = -49.3 \text{ kcal}$$

Since this reaction requires 3 moles of hydrogen to one mole of carbon monoxide, the water shift reaction can be used to adjust this ratio in the medium Btu gas and maximize the yield of methane. Methane is a suitable substitute for natural gas inasmuch as natural gas is composed primarily of methane (85 percent) with lesser amounts of other hydrocarbons and nitrogen. While the relatively low Btu values of low and medium Btu gas from wood gasification preclude storage or transport over any distance, conversion to methane provides a route for the production of a pipeline-quality substitute (950 Btu/sdcf) for natural gas (Bliss and Blake 1977).

Ammonia is manufactured from synthesis gas produced from natural gas by steam reforming, $CH_4 + H_2O \rightarrow 3H_2 + CO$, the reverse of equation 4-3 (Wiseman 1972). The synthesis gas is enriched in hydrogen by the water shift reaction (equation 4-2). Carbon dioxide and small amounts of unconverted carbon monoxide have to be removed as they poison the ammonia synthesis catalyst. Most of the carbon dioxide is removed by scrubbing with a solution of potassium carbonate. After scrubbing, the gas still contains small amounts of carbon dioxide and carbon monoxide; final removal is accomplished by the methanation reaction (equation 4-3). Both carbon monoxide and carbon dioxide are converted into methane, which is left in the hydrogen gas as it does not interfere with ammonia synthesis. In the final step (equation 4-4), ammonia synthesis is carried out by reacting the hydrogen gas with nitrogen gas at high temperature and pressure over an iron catalyst.

$$3H_2 + N_2 \xrightarrow{\text{catalyst}} 2NH_3 \qquad (4\text{-}4)$$
$$\Delta H = -26 \text{ kcal}$$

Ammonia is used to manufacture fertilizers, explosives, nitric acid, and synthethic fibers.

High yields of *methanol* are also obtainable from synthesis gas (Wender in press). The water shift reaction alters the hydrogen to carbon monoxide ratio in the medium Btu gas to that required in equation 4-5.

$$2H_2 + CO \xrightarrow{\text{catalyst}} CH_3OH \qquad (4\text{-}5)$$
$$\Delta H = -26 \text{ kcal}$$

Methanol is a major industrial organic chemical. It is widely used both as a solvent and intermediate for the synthesis of other materials. Its largest use is for conversion into formaldehyde which is important to the forest products industry. Formaldehyde is used to make synthetic resins such as urea-formaldehyde and phenol-formaldehyde. The resins are used in the manufacture of plywood, particleboard, and plastics.

Both ammonia and methanol will have economic competition from coal gasification. Coal to methanol conversion efficiency (59 percent) is higher than that for wood to methanol (38 percent). Furthermore, coal conversion facilities will be larger, making them even more efficient. Ammonia from wood appears more promising than methanol. Wood has a lower carbon to hydrogen ratio than coal which favors the wood feedstock. There is also a possibility that natural gas currently being flared in the Middle East will be converted to methanol or other synthesis gas derivatives and exported (Love and Overend 1978).

Liquid Fuels for Automobiles.—Methanol and ethanol (see chapter 6 for ethanol process) can both be used to fuel modified automobile engines. Such modification includes the use of fuel injection systems as well as some type of induction heating system to improve vaporization of the alcohols (Park et al. 1978ab). Methanol and ethanol can also be blended with gasoline to fuel unmodified automobile engines. Such mixtures are popularly termed gasahol.

Addition of methanol and ethanol increases the octane rating of gasoline, much in the way that tetraethyl lead and other additives do. Potential problems include loss of performance (especially in blends higher than 15 percent alcohol), possible phase separation of the alcohol from the gasoline caused by excessive moisture, and corrosion of fuel system parts. Although these problems will not be difficult to overcome, correction will cost the consumer.

A national gasahol plan for the United States has become a major controversy (Anderson 1978). Proponents contend that by blending 5 to 10 percent ethanol or methanol with gasoline, oil imports could be reduced as much as 20 percent. Opponents indicate the economics are not justified as long as gasoline remains cheaper than the alcohols. The current price of ethanol is $1.25 per gallon while gasoline is $.38 per gallon at the refinery gate (late 1978).

In Brazil, a $400 million program is now underway to produce ethanol from sugar cane and cassava to replace 20 percent of the country's gasoline requirements by the early 1980's (Hall 1978, Hammond 1977). But in Brazil, which imports over 80 percent of its oil, ethanol costs the consumer $1 per gallon compared with $1.50 per gallon for gasoline.

Park et al. (1978ab) indicate in a preliminary report to the Department of Energy that a national gasahol program appears premature. After 1990, the potential for such a program should be more promising. By then, however, methanol and ethanol might be economically converted to gasoline.

A new process to convert methanol into gasoline has been developed by Mobil Research and Development Corporation (Meisel et al. 1976, Chang and Silvestri 1977). The *Mobil process* uses a newly discovered zeolite catalyst to quantitatively convert methanol to hydrocarbons and water.

$$XCH_3OH \xrightarrow{\text{catalyst}} \underset{99+\%}{(CH_2)_X + XH_2O} \qquad (4\text{-}6)$$

Most of the hydrocarbon molecules produced are in the gasoline boiling range (C_4 to C_{10}); total gasoline yield is about 80 percent of the hydrocarbon product. This synthetic gasoline has unleaded Research Octane Numbers (RON) of from 90 to 100. Some of the remaining lower-boiling hydrocarbons can be converted into gasoline by an additional alkylation reaction. When this is done, total gasoline yield approaches 90 percent. The remaining 10 percent is valuable liquified petroleum gas (LPG) (Meisel et al. 1976).

The primary source of methanol for the Mobil process is expected to be coal in the United States and perhaps natural gas in some other countries. However, in some areas it may be economically feasible to use wood as a source of methanol (fig. 4-5).

The *Fischer-Tropsch reaction* also makes hydrocarbons from synthesis gas (Wiseman 1972). The process was used by Germany during World War II to produce both liquid fuels and hydrocarbons for chemical syntheses. The reaction uses a cobalt catalyst at high temperatures to give a complex mixture of hydrocarbons. While gasoline can be made from the process, extensive facilities are needed to separate and upgrade the primary reaction products. Today the process is uneconomical in most countries, but is used in South Africa.

Catalysis.—All of the reactions described above are carried out with *heterogeneous catalysis.* That is the reactants are gases and liquids which come in contact with a solid catalyst. The reactions occur on the surface and in crevices of the catalyst. Heterogeneous catalysis is advantageous because the catalyst can be separated readily from the product stream resulting from the reaction.

Heterogeneous catalysis has been the backbone of the petrochemical industry. Recently, *homogeneous catalysis* (both reactants and catalyst are in solution) by use of metal cluster compounds has been demonstrated for several reactions. Of interest to the utilization of synthesis gas is the reduction of carbon monoxide. *Ethylene glycol,* an important industrial chemical, can be produced in high yield from the reaction of synthesis gas with a rhodium complex.

$$H_2 + CO \xrightarrow{\text{Rhodium complex}} HOCH_2CH_2OH + \text{other alcohols} \qquad (4\text{-}7)$$

$$\underset{\text{ethylene glycol}}{78\%} \qquad \underset{\text{other alcohols}}{22\%}$$

Under certain conditions methanol can also be produced by this approach. While these homogeneously catalyzed reactions will undoubtedly be employed in the future, they are not yet commercially feasible (Wender in press, Anderson in press).

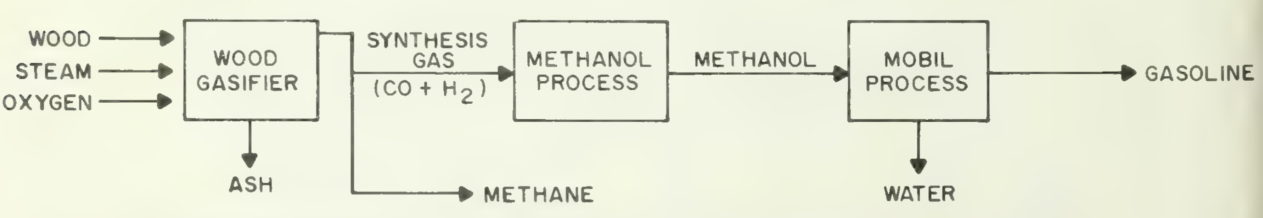

Figure 4-5.—*Overall scheme for the production of gasoline from wood. Selling the methane produced in the gasification step instead of reconverting it into synthesis gas would lower the cost of methanol production. (Drawing after Meisel et al. 1976.)*

CHAPTER 5

Pyrolysis

Pyrolysis is the thermal decomposition of organic matter in the absence of air. The heat to initiate the process can be applied externally, or as is common in charcoal manufacture, part of the wood may be burned by air combustion to generate the heat necessary to start the pyrolysis process (U.S. Forest Prod. Lab. 1961). Pyrolysis is generally carried out at lower temperatures than gasification and is primarily for producing solid or liquid fuels.

In the past, pyrolysis was referred to as destructive distillation. Principal marketable products from a hardwood distillation industry 30 years ago were acetic acid, methanol, and charcoal (Beglinger 1948). Distillation was carried out in externally heated ovens and retorts. Today, methanol and acetic acid are produced much more cheaply by the petrochemical industry. However, wood charcoal remains an economically viable product.

Most charcoal produced in the United States today is processed into briquets for cooking. Some is used as an industrial fuel and some for metallurgical processing and some to make activated carbon (Baker 1977, Walker in press). In the near future, wood charcoal may be slurried with high-sulfur oil or mixed with high-sulfur coal before pulverization to make a fuel which would have lower sulfur dioxide emissions and thus possibly comply with air pollution regulations (Bliss and Blake 1977). Additionally, the charcoal-oil slurry could help reduce reliance on imported oil. Technically, both processes are expected to be feasible, but a problem may come about in securing a reliable charcoal supply for the large, conventional oil- and coal-fired central stations where this is proposed.

Wood is also suitable for making activated carbon. This can be done by steam activation of wood charcoal; yield is generally around 12-15 percent based on the weight of the dry wood (Baker 1977). Little activated carbon is made from wood today because that made from coal and coconut hulls is sufficient to supply the market. However, the EPA is considering requiring the use of activated carbon by all water treatment plants. The EPA has found suspected carcinogens such as chloroform and carbon tetrachloride in municipal water systems, and activated carbon can remove these agents. Today, the main markets for activated carbon are for water and waste water treatment, air pollution control systems, catalyst supports, sugar decolorization, and auto evaporation control systems. About one-third of the market is for water and waste water treatment (Walker in press).

In the United States, most wood charcoal is now produced either in a batch process using Missouri-type kilns or in a continuous process using a Herreshoff multiple-hearth furnace. Other continuous processes recently have been developed which can be used to produce liquid and gaseous fuels as well as charcoal (Bliss and Blake 1977, Baker 1977).

5-1 Charcoal Formation in Kilns

Ignition, coaling, and cooling are the three stages in the formation of charcoal from wood (Hallett 1971). These stages are readily distinguished when describing the production of charcoal by batch processes.

Ignition is endothermic (requires heat) and requires considerable air (U.S. Forest Prod. Lab. 1961). The wood is first ignited with kindling and kerosene and allowed to burn. Temperatures in the kiln rapidly rise to about 1,000°F and then drop when most of the starter fuel has been consumed. Coaling begins around 540°F, and at that temperature the process becomes exothermic (gives off heat). When the coaling stage is reached, the amount of air is restricted to control kiln temperature and to ensure that the wood will form charcoal and not burn to ash. For the production of good quality charcoal, kiln temperatures of 850° to 950°F are maintained during coaling.

After coaling, the kiln is completely sealed to exclude all air and allowed to cool. When temperatures are 150°F or less, it is generally safe to open the kiln.

A complete cycle, from ignition through cooling, may require 6 to 7 days. Typical charcoal produced from wood will have a higher heating value of about 12,000 Btu/lb. Proximate analysis will be about 20 to 25 percent volatile matter and 75 to 80 percent fixed carbon on a moisture free and ash free basis. Ash content is generally about four times that of wood (Peter 1957, Baker 1977, U.S. Forest Prod. Lab 1961).

The transformation of wood into charcoal has been studied recently by simulating commercial charring conditions in the laboratory (Slocum et al. 1978). Most work has been done on oak and hickory. Study of mass loss, shrinkage, and physical properties of charcoal produced under various coaling conditions will lead to a better understanding of this very complex and incompletely understood process (McGinnes et al. 1971, Anon 1975). Analytical techniques that have been found especially useful for these studies include the use of scanning electron microscopy to follow shrinkage and small angle X-ray analysis to evaluate micropore formation in the charcoal (von Bastian et al. 1972, Blankenhorn et al. 1972, Beall et al. 1974, McGinnes et al. 1974, McGinnes et al. 1976).

In the past, small-scale charcoal production was accomplished with a variety of kilns. As any relatively air-tight structure with properly placed smoke and draft vents can be used to produce charcoal, small kilns with capacities of 1/2 cord to 10 cords or more were popular through the late 1950's (fig. 5-1) Such kilns varied considerably in construction and size; building materials commonly were cinder blocks, bricks, stone, metal, and reinforced concrete. Yields of charcoal varied greatly in the kilns, even under optimal operating conditions. In cinder block kilns typical yields for seasoned hardwoods averaged around 900 lb of charcoal per cord and slightly less for unseasoned hardwoods (Witherow 1956, Witherow and Smith 1957, Peter 1957, Page and Wyman 1969, U.S. Forest Prod. Lab 1961).

Today, over half of the Nation's wood charcoal is produced in Missouri-type kilns (Baker 1977). Missouri-type (fig. 5-2) kilns use roundwood or sawmill slabs. Typically the kilns are made of poured concrete and have an average capacity of 50 cords. Some, however, hold up to 100 cords. White oak and hickory are the two major species of wood used.

5-2 Herreshoff Multiple-Hearth Furnace

The Herreshoff multiple-hearth furnace uses hogged wood or bark to produce charcoal in a continuous process (fig. 5-3). Production rates range from 1 to 4 tons per hour. As these units operate continuously, they must be fed a steady supply of wood. The smallest of these furnaces requires about 100 tons of wood per day on a dry basis. With wood that has moisture content of 40 percent, the production rate of charcoal is about 1 ton per hour.

The Herreshoff furnace consists of several hearths stacked one on top of the other and enclosed in a cylindrical, refractory-lined steel shell (Nichols Engi-

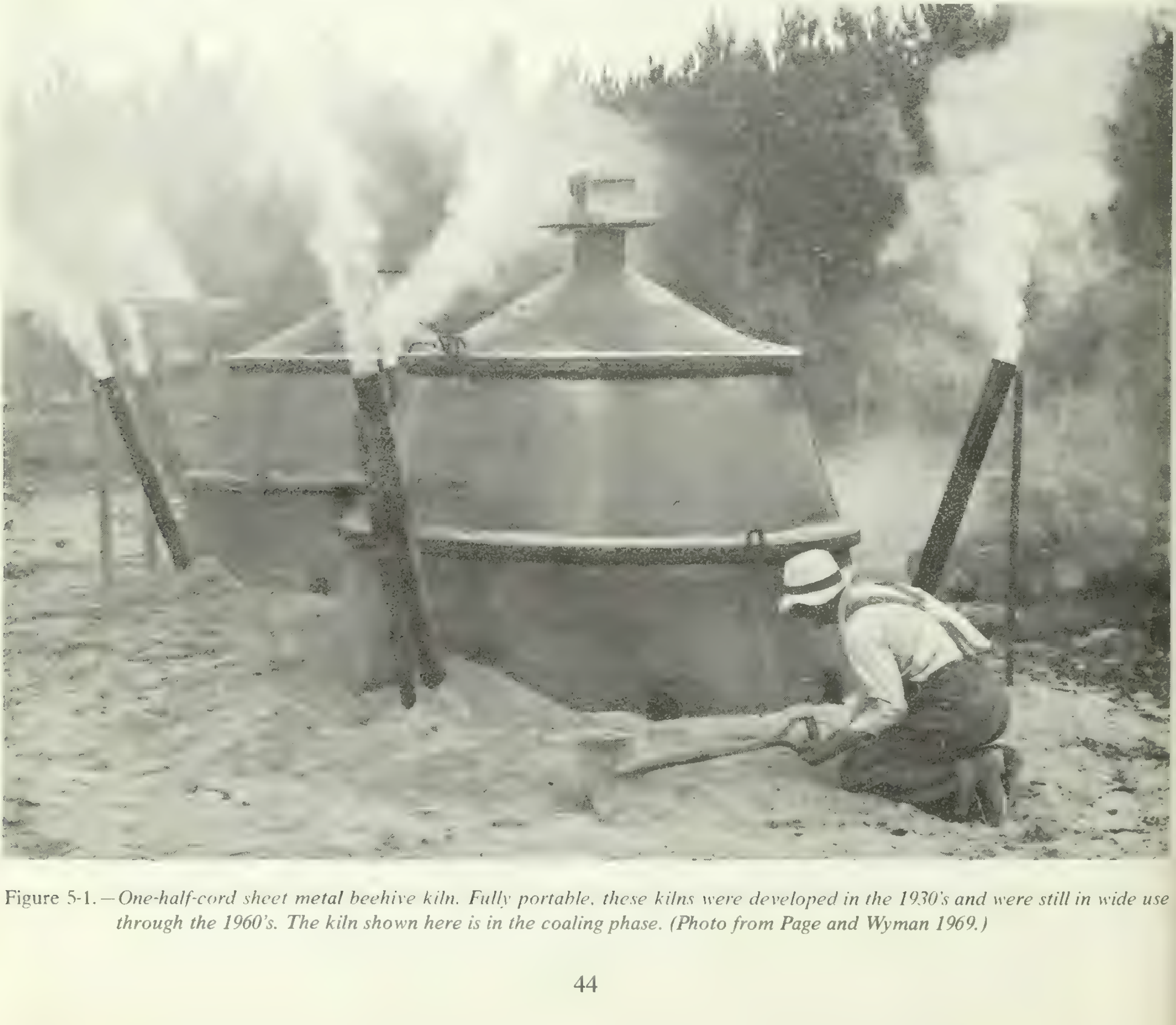

Figure 5-1.—*One-half-cord sheet metal beehive kiln. Fully portable, these kilns were developed in the 1930's and were still in wide use through the 1960's. The kiln shown here is in the coaling phase. (Photo from Page and Wyman 1969.)*

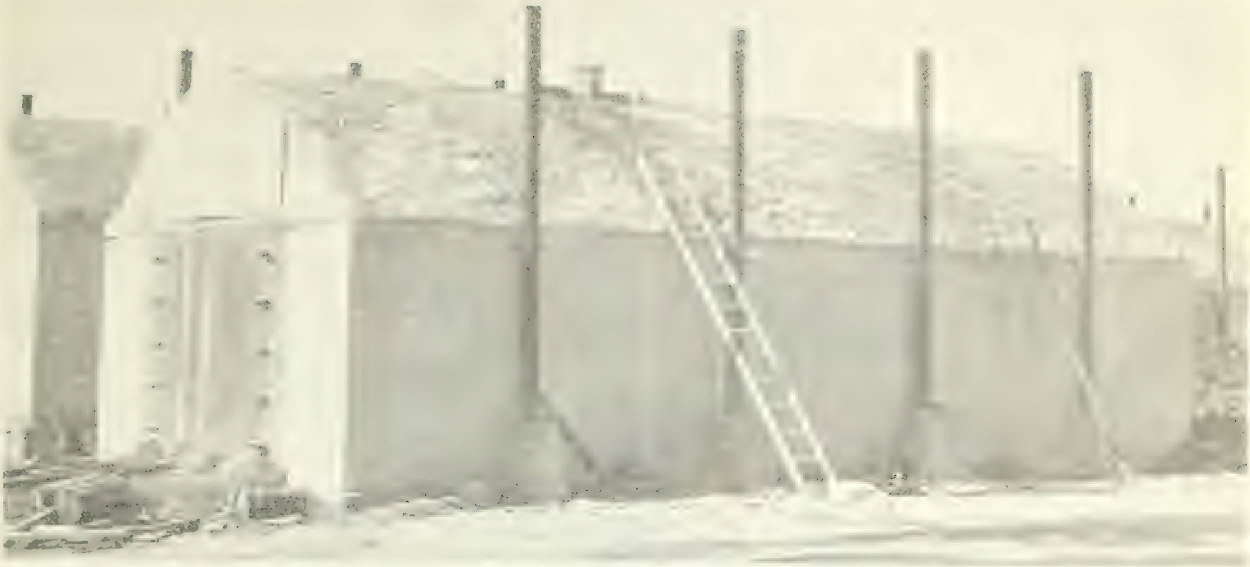

Figure 5-2.—*Missouri-type batch kiln. (Photo courtesy of Bob Massengale, Missouri Department of Conservation.)*

neering and Research Corp. 1975, Bliss and Blake 1977). Passing up through the center of the furnace is a shaft which carries arms with rabble teeth. As the shaft turns, the teeth constantly plow through and turn the fuel over while moving it in a spiral path across the hearth floors toward drop holes that connect each hearth. The drop holes alternate on each hearth floor between the inner periphery (around the shaft) and the outer periphery of the hearth. The rabble teeth are alternately angled so that the material moves in the direction of the next set of drop holes. In this way material fed at the top of the furnace is spread over and across each hearth floor in a radial flow that alternates inwardly and outwardly until the charcoal is finally discharged from the bottom of the furnace. Material is dried, heated, and carbonized as it passes downward through the furnace while hot combustible gas produced passes upward in a current counter to the flow of the material (fig. 5-4).

Heat for startup is provided by gas- or oil-fired burners mounted in the sides of the hearths. When the proper furnace temperature has been attained, the auxiliary fuel is turned off. To sustain pyrolysis, sufficient combustion air is allowed into the furnace to burn some of the volatile gases produced. Air entry is regulated to maintain furnace temperatures at 900 to 1200°F. The evolving combustible gases are more than that needed for drying and carbonizing the wood and can also be burned in a boiler after they exit the furnace. With a heating value of about 200 Btu per sdcf plus the sensible heat of the exhaust temperature, the pyrolysis gases from the production of 2 tons of charcoal per hour can generate about 50,000 lb per hour of high pressure steam (Bliss and Blake 1977). Yield of charcoal will vary with moisture content of the feed; about 8 tons of wet wood (50 percent MC) are required to produce 1 ton of charcoal.

5-3 Tech-Air System

Knight and Bowen[9] describe a steady-flow pyrolysis system that produces a pyrolytic oil, charcoal, and off gases. The oil, which has a heating value of 10,000 to 13,000 Btu/lb, is obtained by passing the pyrolysis vapors through a condenser. Remaining non-condensable gases which contain about 200 Btu/sdcf, are used to pre-dry incoming wood fuel (fig. 5-5). Incoming fuel is pre-dried to about 4 percent moisture content before entering the converter or pyrolysis unit. The non-condensable gases are sufficient to pre-dry fuel of up to 50 percent moisture content. About 35 percent of the energy content of the wood fuel is in the charcoal and about 35 percent in the pyrolytic oil. On a weight basis, charcoal yield is 23 percent while pyrolytic oil yield is 25

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[9] J. A. Knight and M. D. Bowen. Pyrolysis—a method for conversion of forestry wastes to useful fuels. 13 p. Paper presented at the Southeast. Tech. Div. of Am. Pulpwood Assoc. fall meeting. (Atlanta, Ga., Nov. 5-6, 1975).

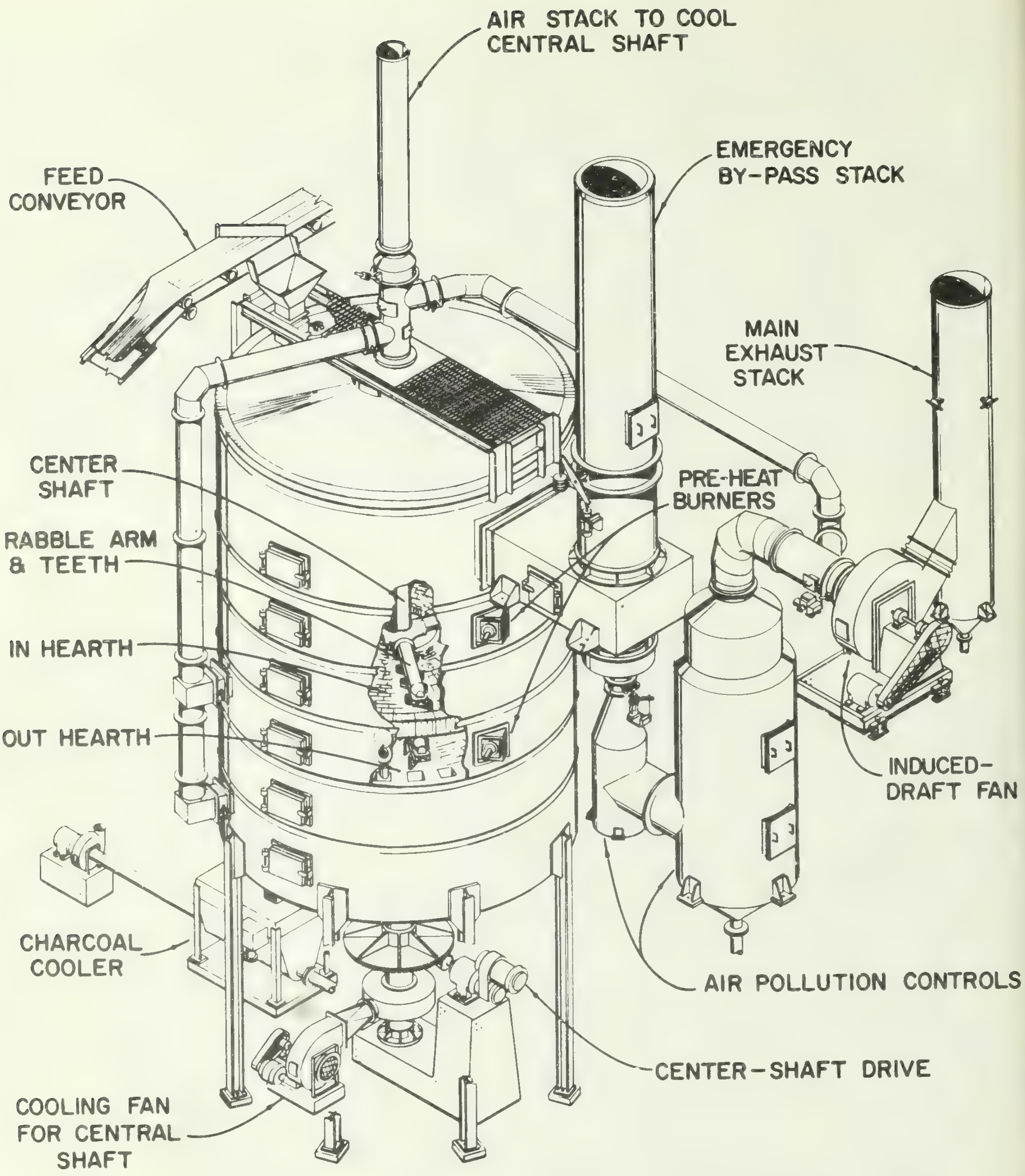

Figure 5-3.—*Nichols-Herreshoff multiple hearth furnace for the production of wood charcoal. (Drawing from Nichols Engineering and Research Corporation.)*

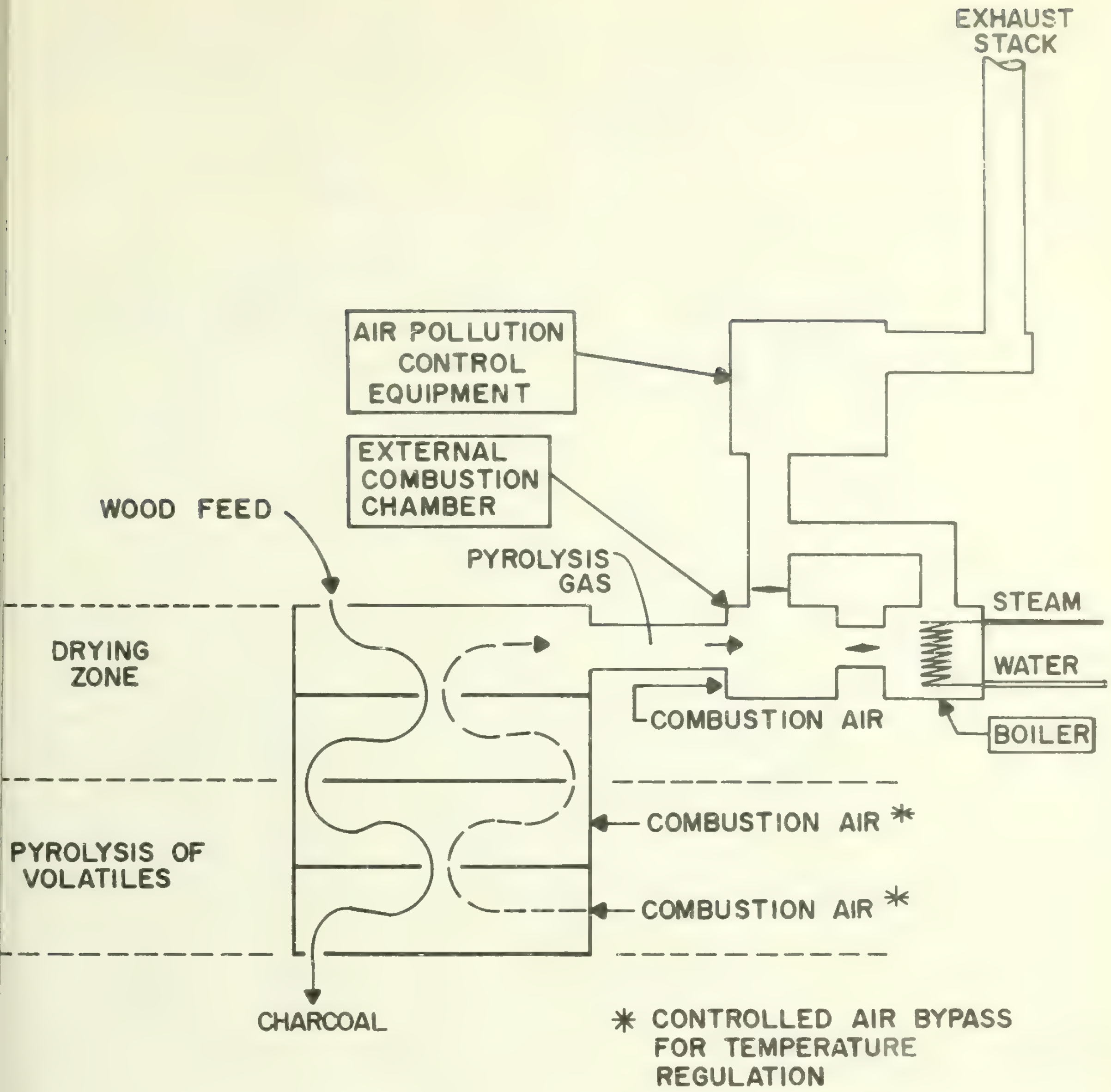

Figure 5-4.—*Feed and gas flow diagram for the Nichols-Herreshoff multiple hearth furnace.*

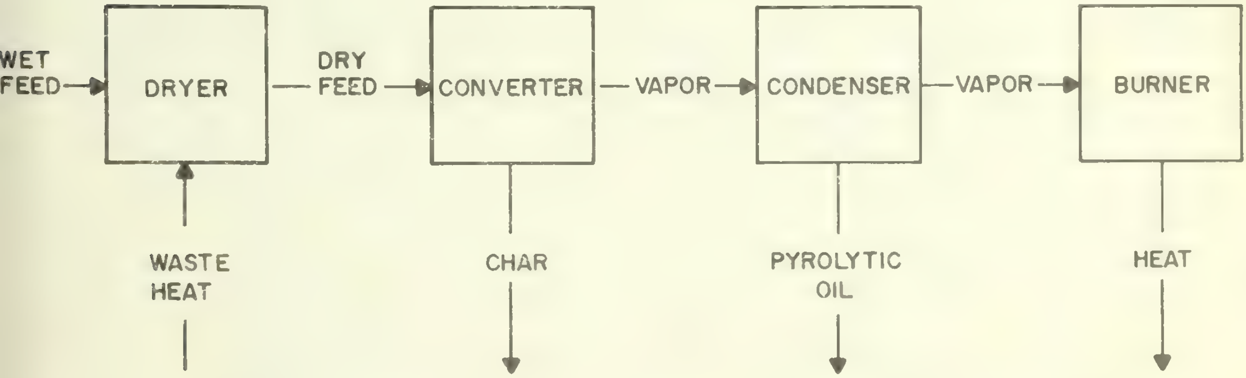

Figure 5-5.—*Block flow diagram for the Tech-Air pyrolysis system. (Drawing after Knight and Bowen[9])*

percent. Charcoal heating values ranges from 11,000 to 13,500 Btu/lb. The process has been operated on a scale of 50 dry tons of fuel per day, and processing up to 200 tons per day appears feasible (Bliss and Blake 1977).

5-4 Occidental Flash Pyrolysis

Preston (1975) describes a pyrolysis system that internally recycles the charcoal produced in order to supply heat energy for the pyrolysis process. The primary products are pyrolytic oil, off-gases, and water. The process was developed primarily for pyrolyzing municipal refuse while recovering valuable metals and glass (fig. 5-6). It is presented here because the process will work as well, maybe better, with wood feed. Of course, the glass and metal recovery systems will not be needed.

This pyrolysis is aimed at producing a maximum yield of combustible liquid or oil. Pyrolysis is carried out on finely shredded organic material which is carried into the reactor by recycled off-gases. Pyrolysis takes place at 950°F at about 1 atmosphere and with short residence time. The charcoal is separated from the product stream by cyclone separators and then combusted in the charcoal burner. The remaining pyrolytic vapors are rapidly quenched to prevent further cracking of the oils. At this point, the products are separated into pyrolytic oil, gas and water. The pyrolytic oil (10,600 Btu/lb) produced is intended to be sold as a substitute for No. 6 residual (Bunker C) fuel oil. The pyrolysis gases have a heating value of about 380 Btu/sdcf, are recycled for use as a transport medium, and eventually are burned to provide heat to the rotary-kiln dryer.

CHAPTER 6

Other Processes

6-1 Liquefaction

Wood can be converted to an oil by reaction with synthesis gas and an alkaline catalyst under high temperature and pressure (Lindemuth 1978) (fig. 6-1). Part of the wood can be used to produce the synthesis gas by gasification. Preparation includes drying and grinding the wood before blending with recycled oil to produce a wood oil slurry of about 30 percent solids. The slurry, synthesis gas, and the alkaline catalyst (sodium carbonate solution) are then reacted at 600° to 700°F and 2,000 to 4,000 psi for various lengths of time. The oil is separated from unreacted wood and ash and part is recycled to blend with incoming wood. The waste stream contains catalyst and unreacted wood.

In the original process, which was developed by the U.S. Bureau of Mines, carbon monoxide plus steam and/or hydrogen was used as a reducing mixture in the presence of alkaline catalysts (Na_2CO_3 or HCO_2Na) at temperatures up to 750°F and pressures as high as 5,000 psi (Appel et al. 1975). Under these conditions it was found that cellulosic materials such as urban refuse, sawdust, bovine manure, and

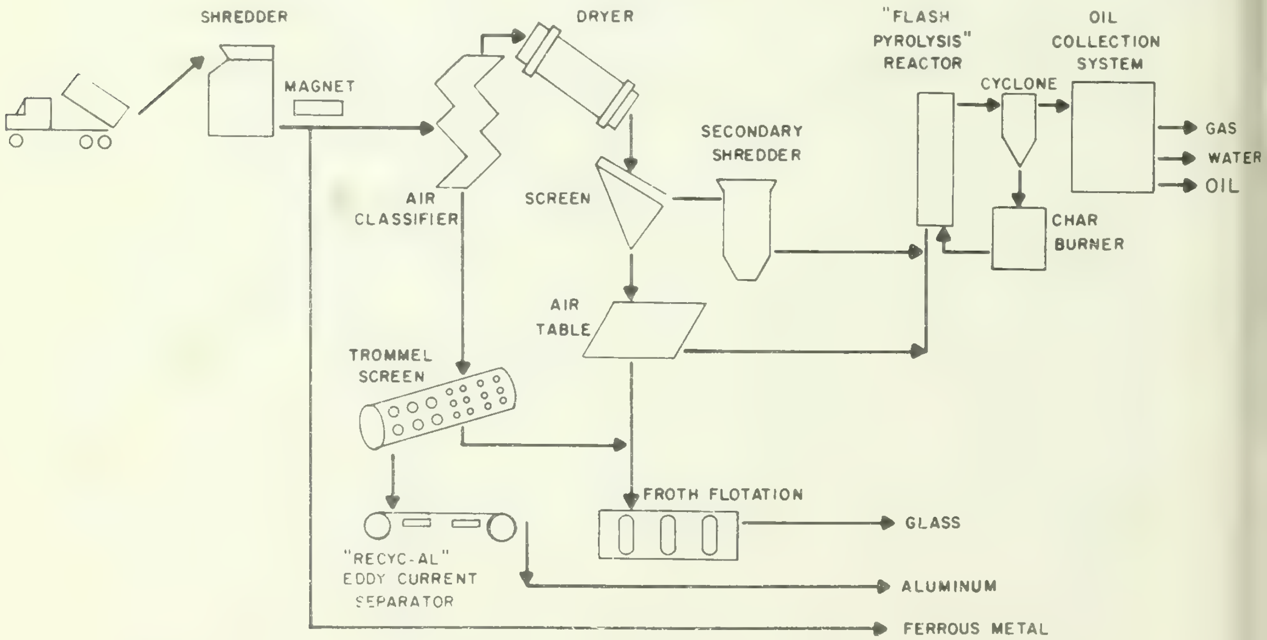

Figure 5-6.—*Simplified flow diagram for the Occidental resource recovery system. (Drawing after Preston 1975.)*

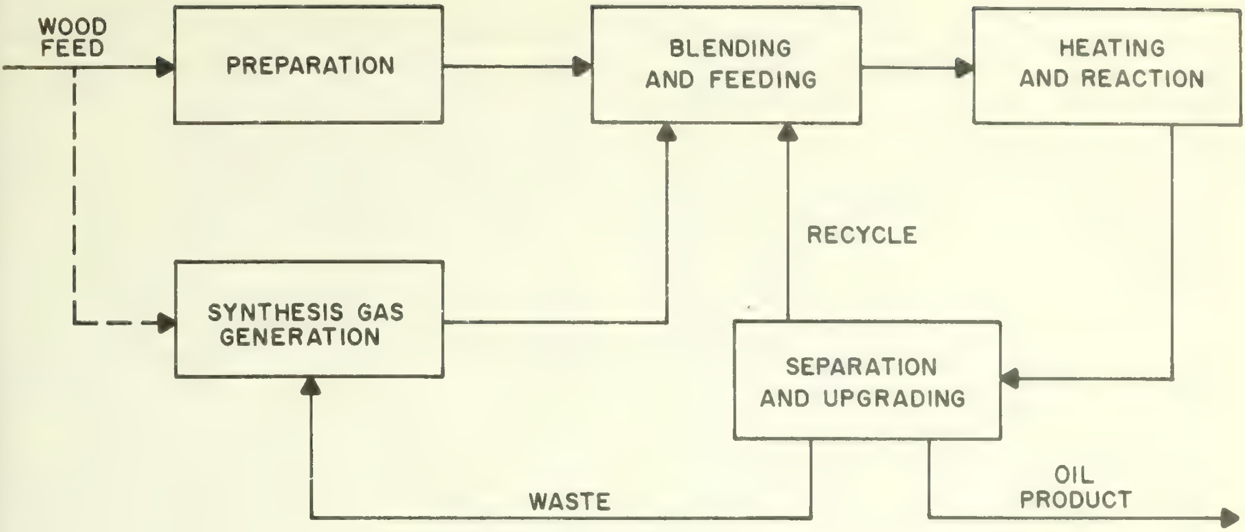

Figure 6-1.—*Wood liquefaction scheme. (Drawing after Lindemuth 1978.)*

sewage sludge could be converted to heavy oils. However, it was noted that materials containing larger quantities of lignin or other non-carbohydrates may require more severe reaction conditions. Bark, which has a high phenolic content that would consume considerable quantities of the alkaline catalyst, may not be suitable for this process as originally designed.

A unit in Albany, Oregon is testing the feasibility of using the U.S. Bureau of Mines process to liquefy wood and other biomass on a large scale. Incoming wood chips, which normally have a moisture content of about 50 percent, are dried to about 1 to 5 percent moisture content in a gas-fired rotary drier. The dried wood is then hammermilled to about 50 mesh before being slurried with recycled product oil. A catalyst solution of sodium carbonate is added and carbon monoxide gas is sparged through the mixture. Results to date have indicated reaction times of 25 to 30 minutes should be adequate for a commercial plant. Product yield ranges from 40 to 50 percent. On a volume basis, the heating value of the wood-produced oil is about four times higher than that of wood. The viscosity of the oil is high and has presented some problems in mobility (table 6-1). Current research at the Albany plant is aimed at solving problems of viscosity buildup and purification of the oil (Lindemuth 1978).

Table 6-1.—*Average properties of wood produced oil (Lindemuth 1978)*

	Reactor residence time	
	20 min	60 min
Viscosity @ 100° L.Cp	10,000-20,000	3,000-12,000
Heating value Btu/lb	15,700	16,000
Elemental analysis		
% C	86.0	88.3
% H	6.4	6.7
% O	6.4	4.0
% N	0.4	0.1

6-2 Hydrolysis and Fermentation

Cellulose and hemicelluloses, the principal polymeric carbohydrates (polysaccharides) of wood, can be converted into simple hexose (six carbon) and pentose (five carbon) sugars by hydrolysis. Cellulose, which is a linear polymer of β $(1 \rightarrow 4)$ linked anhydroglucose units, yields the hexose sugar glucose. Hemicelluloses are composed of several different polysaccharides. In the pine-site hardwoods the major hemicellulose is an acetylglucuronoxylan.[10] Hydrolysis of the pine-site hardwood hemicelluloses predominantly yields the pentose sugar xylose. Lesser amount of other constituents will also be released from the hemicelluloses, as follows: arabinose (a pentose sugar); glucose, galactose, and mannose (hexose sugars); and glucuronic acid.

An insoluble lignin residue can also be recovered from wood hydrolysis processes by centrifugation or filtration (Hoyt and Goheen 1971). Called hydrolysis lignin, this material is condensed and contains some unhydrolyzed cellulose residues. Hydrolysis lignin should not be confused with kraft lignin or sulfite lignin, residues from pulping processes (Sarkanen and Ludwig 1971).

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[1] Unpublished data from H. L. Hergert, ITT, Rayonier, New York, N.Y.

The three major products of pine-site hardwood hydrolysis, glucose, xylose, and lignin, potentially can be used in a number of ways. At present, using them to produce ethanol, furfural, and phenol is of much interest (fig. 6-2).

Ethanol is used as a solvent to manufacture pharmaceuticals and perfume and as an intermediate in organic syntheses. It could be used as a clean burning fuel and can be mixed with gasoline to make gasohol. In the United States, most ethanol is produced by the petrochemical industry from ethylene.

Fermentation to produce ethanol is an old, well established process. In one approach that might be taken with a pine-site hardwood hydrolysis mixture, glucose and the other hexose sugars can be selectively fermented to ethanol by *saccharomyces* yeast. Xylose and arabinose are left unchanged, and the xylose can be recovered by crystallization (Herrick and Hergert 1977).

The dehydration of pentose sugars such as xylose to *furfural* is a well known acid-catalyzed reaction that is favored by high temperature and pressure. Current production of furfural in the United States is from pentose-rich agricultural residues such as corn cobs, grain hulls, and sugar cane bagasse. Furfural is used as a solvent and as an intermediate for the production of furan derivatives.

The largest use of *phenol* is in producing plywood adhesives. Thus, the phenol market fluctuates with demand for new housing. Phenol is also used in molded products and adhesives that are used in automobile and appliance manufacture.

Today, nearly all phenol is made from cummene, a petrochemical, but various hydrogenolysis techniques also can produce phenols from lignin. Reportedly, yields in the neighborhood of 40% of monomeric phenol derivatives have been obtained in pilot-plant experiments (National Research Council 1976). However, hydrodealkylation of the mixture of phenol derivatives to a high yield of phenol is not a proven process.

Other potential uses for the hydrolysis products of pine site hardwoods include the production of *Torula* yeast, a protein supplement (Herrick and Hergert 1977). Unlike fermentation to ethanol, which utilizes only the hexose sugars, both hexose and pentose sugars, certain sugar acids, and carbohydrate fragments can be used to grow the yeast. A reagent such as Raney Nikle or a hydrogenation catalyst can reduce xylose and glucose to xylitol and sorbitol, their corresponding sugar alcohols. Hydrolysis lignin can be used as a soil conditioner, filler for resins and rubber, depressant in ore floatation, decay-retardant in fabrics, a binding agent for particle and hardboard, and a grinding aid for Portland cement (Hoyt and Goheen 1971). In the Soviet Union, much of the hydrolysis lignin is burned as fuel. However, the high moisture content must be removed first. In one process, the lignin is dried to 12-18 percent moisture content with hot flue gases and then pressed into briquettes. It has also been suggested that hydrolysis lignin be used as a source of activated carbon (National Research Council 1976).

Hemicelluloses are readily hydrolyzable under mild acidic conditions; cellulose, on the other hand, is much more difficult to hydrolyze because of its crystalline organization and stable structure. Efficient production of sugars from whole-wood hydrolysis must take into account this difference or a competing reaction in which sugars are destroyed can occur (Harris 1975).

There are a number of potential wood hydrolysis processes (Oshima 1965, Wenzl 1970, Titchener 1976, Bliss and Blake 1977, Karlivan in press). The processes use hydrochloric acid, sulfuric acid, or enzymes (table 6-2). The acid-catalyzed processes can be further divided into those using dilute or concentrated acids. Hydrolysis with dilute acids is carried out in a single stage at elevated temperature and pressure. Concentrated-acid processes are generally conducted in two stages, a prehydrolysis and

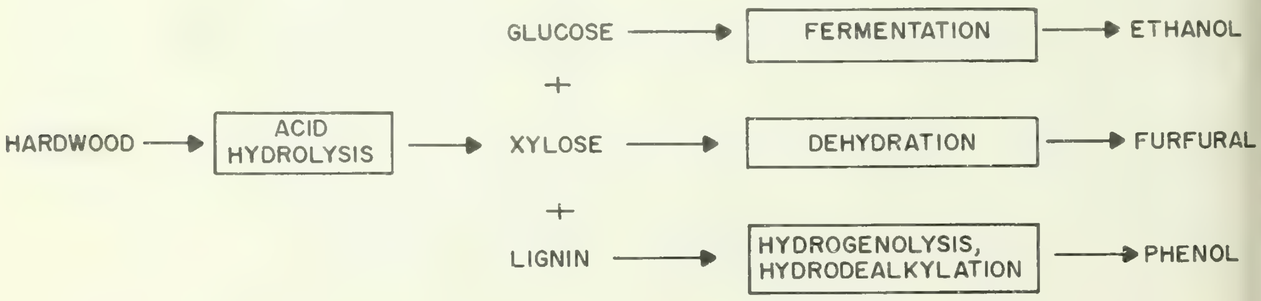

Figure 6-2.—*Production of ethanol, furfural, and phenol from pine-site hardwoods by hydrolysis.*

Table 6-2.—*Some processes for wood hydrolysis* (Bliss and Blake (1977).

Name	Main hydrolysis conditions			Yield of Fermentable Sugar (kg/t wood)	Sugar Concn (wt %)	Recovery method for medium	Status
	Medium	Temp. (°C)	Time (h)				
Scholler	1/2-1% H_2SO_4	180	12	352	4	As $CaSO_4$	Several plants operated in Europe before and during World War II
Madison	1/2-% H_2SO_4	180	3	>352	5.5	As $CaSO_4$	Demonstration plant built 1946 and 1952
Hokkaido	80% H_2SO_4	40	>1	—	20	Ion exchange to recover 25-35% acid	100 T/D plant at Asahikawa in 1963
Rheinau-Udic	41% HCl	20	About	—	10	Vacuum distillation	Semi-commercial plant (2000 ODT/yr operated (1959)
Noguchi-Chisso	HCl gas	50	>1	–	30	Vaporization using hot air	1 t/d plant operated (1956)
U.S. Army Natick Development Center	Enzymes	50	48	90-220	1.6-4.6	–	Experimental bench-scale

a main hydrolysis stage that is kept near ambient temperature.

Dilute acid processes are typified by the *Scholler-Torensch process* which uses 0.5 percent sulfuric acid to complete hydrolysis in one stage at elevated temperature and pressure. Dilute acid is percolated through wood chips or sawdust followed by a charge of steam. The short hydrolysis time does not completely hydrolyze the cellulose, so the acid-steam percolation is repeated up to 12 times. The dilute sulfuric acid in the hydrolyzate is neutralized by calcium carbonate to form calcium sulfate ($CaSO_4$) which is removed by filtration. The yield of sugar on a weight basis is around 40-50 percent for softwoods (Titchener 1976, Bliss and Blake 1977).

The *Madison process* is a continuous-flow variation of the Scholler-Torensch process. A continuous flow of reagent removes the hydrolyzate to a cool zone to reduce sugar degradation. Total saccharification time is about one-fourth of that required in the Scholler-Torensch process, thus lowering the production cost. Hardwoods yield about 35 percent fermentable sugars and 20 percent pentoses on a weight basis (Titchener 1976, Herrick and Hergert 1977).

A typical example of a concentrated-acid process is the *Rheinau-Bergius process* which was used by Germany in World War II to produce yeast from hydrolyzed sugars. In stage one, fuming hydrochloric acid (up to 41 percent) is used to degrade cellulose mostly to lower oligomers at ambient temperatures. In the second stage, the acid is diluted with water and heated to yield monomeric sugars. In the *Rheinau-Udic process,* a modification of the earlier procedure, prehydrolysis, is carried out with a 32 percent acid solution and the main hydrolysis uses 41 percent hydrochloric acid. The hydrochloric acid is recovered by vacuum distillation. The hydrolyzate is post-hydrolyzed, filtered, decolorized, and passed through an ion-exchange column, before crystallization of the glucose. Reportedly, 22 kg of crystalline glucose can be obtained per 100 kg of wood (Wenzl 1970).

The use of hydrogen chloride gas, rather than concentrated hydrochloric acid, is the basis of several proposed processes (Titchener 1976). In the Japanese *Noguchi-Chisso process,* wood is first prehydrolyzed to remove hemicelluloses. The residue is heated with a 5 percent hydrochloric acid solution and cooled. Gaseous hydrogen chloride is then administered; the temperature is kept below 10°C. Next, the temperature is raised to 40°C to effect hydrolysis to lower oligomers. The hydrogen chloride is recovered by blowing hot air through the hydrolyzate. Post-hydrolysis at 100°C with 3 percent hydrochloric acid yields glucose. In this step, acid is recovered by vacuum distillation.

The advantages of this system are the simplicity of acid recovery, fewer corrosion problems, and the sugar solutions are more highly concentrated.

In the *Hokkaido process,* first prehydrolysis is carried out with steam or dilute sulfuric acid at temperatures up to 185°C. A furfural yield of 65 to 75 kg per tonne of dry wood is obtained from dehydration of the pentoses in the reactor. The prehydrolysis residue is then dried, powdered, and treated with 80 percent sulfuric acid for about 30 seconds. The reaction mixture is immediately washed with water and filtered. Acid is recovered by use of ion-exchange resins. The hydrolyzate, which still contain dilute sulfuric acid, is post-hydrolyzed by heating at 100°C. Yield of crystalline glucose is about 280-290 kg/ton of dry wood (Bliss and Blake 1977).

Interest in enzymatic hydrolysis of cellulose to glucose has been spurred by the United States Army Natick Development Center's development of strains of *Tricoderma* fungi. These fungi produce cellulase enzymes that have been tested on several cellulosic substrates (Mandels et al. 1978, Bliss and Blake 1977).

The *enzymatic hydrolysis process* requires two stages. In the first, the enzyme is produced by growing the fungus in a culture medium of cellulose pulp. After a period of growth, the broth is filtered to give the enzyme-containing solution used in hydrolysis. Hydrolysis generally is carried out at pH 4.8 and 50°C on ball-milled cellulosic substrates. Pulverization by ball milling is necessary to break down cellulose crystallinity. Yields depend on the substrate and range from 16-77 percent. Pure cellulose pulp and shredded paper give respectable yields of up to 77 percent. Wood waste, on the other hand, yielded only 16 percent reducing sugars. On pulped wood chips the yield was 57 percent (Mandels et al. 1978, Bliss and Blake 1977).

While these enzymes may lead to a non-corrosive process (as opposed to acid hydrolysis), they require pretreatment of the wood cellulose because they are greatly inhibited by the cellulose crystallinity and the ligno-cellulosic complex. In fact, lignocellulosics present a formidable barrier for most enzyme systems. Thus, utilization of wood to produce methane gas by anaerobic digestion using bacteria or use of wood as food for ruminants is not yet fully practical. However, wood is used as a roughage for ruminant rations (Baker et al. 1975). The best possibility for overcoming the low reactivity of wood is to develop a cost-effective pretreatment that makes lignocellulosics react to enzymatic hydrolysis (Millett et al. 1975).

6-3 Prehydrolysis

An alternative to whole-wood hydrolysis is to remove the hemicelluloses for chemical or other use in a mild prehydrolysis step, and then to use the remaining fibrous cellulose residue in a pulping process or for particleboard or fiberboard manufacture or for fuel (fig. 6-3, Herrick and Hergert 1977).

Prehydrolysis can be carried out by hot water extractions. Acids in the wood and those released by hydrolysis cause extensive depolymerization of hemicelluloses. The resulting water soluble carbohydrates are mostly low molecular weight polysaccharides with smaller amounts of monomeric sugars. Yield and composition depend on temperature and time of extraction. Typically, water temperatures of 100° to 170°C and extraction time of 30 minutes are sufficient. The polysaccharides containing xylose units (xylans) are more easily hydrolyzed than the corresponding glucans; thus, prehydrolysis of hardwoods for recovery of xylose can be accomplished at lower temperatures than for hemicellulose removal from softwoods. Typically the hot water prehydrolyzate of hardwood will contain polymers of xylose (30 percent) and glucose (25 percent) (Herrick and Hergert 1977).

Hemicellulose extracts have been marketed since 1965 as Masonex, an ingredient of livestock feed (Galloway 1975). The fibrous residue or pulp is used to manufacture hardboard. Only steam and pressure are used to pulp the wood chips and so the hemicellulose fractions removed are not contaminated by added chemicals. The hot water extract is separated from the pulp by vacuum filtration and concentrated by evaporation to 65-percent solids. The resulting product resembles molasses and can be added in cattle feed to 10 percent by weight. Reportedly, the product contains 890 kilocalories of metabolizable energy per gallon (10.4 lb).

Funk (1975) describes a prehydrolysis process that enables recovery of up to 80 percent of the hemicelluloses, mainly as the monomeric sugar xylose. The process does not seriously affect the fiber residue. The degree of polymerization of the residual cellulose is on the order of 900 DP with viscosity between 30 and 40 centipoise.

In the process, organic acids (acetic and formic) are vaporized and injected with steam into the digester where the wood chips are. Reaction time ranges from 15 minutes to 1 hour and the temperature is kept below 135°C. Above 135°C, xylose degradation and fiber deterioration occur. More acids are generated in this process than are injected, so acid recovery by vacuum distillation is feasible. Xylose can be separated from glucose and other sugars by selective crystallization or microbial conversion. An alternative is to reduce the product mixture and separate the sugar alcohols.

When furfural is desired as the product from a hardwood prehydrolysis process, it may be advantageous to add some dilute sulfuric acid. The dilute mineral acid helps to produce furfural by removing and hydrolyzing the hemicelluloses and dehydrating xylose. Thus, it is possible to produce furfural in a one-stage process in which both hydrolysis and dehy-

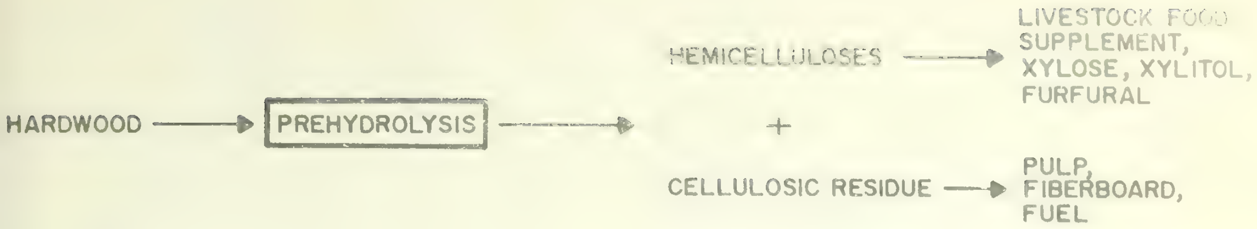

Figure 6-3.—*Prehydrolysis of pine-site hardwoods for chemical, animal food supplement, and fiber or fuel use*

dration occur in the reaction vessel. Harris (1978) indicates that the residue from such a process can supply more fuel for heat energy than the process requires.

CHAPTER 7

Industrial Use of Wood Energy

The forest products industry is the fourth largest user of purchased energy in the Nation (U.S. Forest Service 1976). (The petroleum, chemical, and primary metals industries are the three largest users.) In 1974 the forest products industry purchased about 1.8 quads, or slightly more than 2 percent of the Nation's total energy use (Salo et al. 1978). About 1.3 quads were fuel oil and natural gas, energy sources particularly vulnerable to curtailment and interruption.

The industry also generates much of its own energy from mill wastes and residues. Pulp and paper mills generate the most by burning spent pulping liquors, wood, and bark. Nationally, pulp and paper mills are about 40 percent energy self-sufficient, sawmills about 20 to 40 percent, and plywood and veneer mills, about 50 percent (U.S. Forest Service 1976). At 50 percent, southern pulp and paper mills are more energy self-sufficient than the national average (table 7-1). However, they also purchase more energy than anyone else in the forest products industry (table 7-2).

Most fuel, purchased and residue, is burned to generate steam which satisfies most of the process requirements for the industry. However, some electricity is also generated in the industry by co-generation. Pulp and paper mills in general produce only about one-half of their electrical needs, but sawmills could sell excess electricity if the economics were favorable (Pingrey and Waggoner 1978).

Table 7-1.—*Energy use pattern for southern pulp and paper mills*[1]

Energy source	Percent total energy used
Electricity	3
Natural gas	20
Oil	20
Coal	7
Pulping liquors	43
Wood and bark	7

[1] Data from U.S. Forest Service (1976).

Table 7-2.—*Energy purchased by the pulp and paper sector by geographical area*[1]

Geographic area	Energy purchased	
	10^{12} Btu's	*Percent*
South	806	62
North	286	22
Rocky Mountain	26	2
Pacific Coast	182	14
Total	1,300	100

[1] Data from U.S. Forest Service (1976).

The forest products industry is in a good position to achieve greater energy self-sufficiency by burning more wood and bark residues to replace or supplement purchased fossil fuels (Grantham 1978, Salo et al. 1978, Pingrey and Waggoner 1978, Benemann 1978, Hodam 1978). Such action would also free oil and natural gas for use elsewhere as a fuel or petrochemical feedstock. Because of its proximity to vast amounts of virtually unused pine-site hardwoods, the forest products industry in the South has a better opportunity than anyone else in the country to convert to wood fuel.

The industry already has experience in handling such bulky wood materials. However, certain problems will have to be addressed, mainly storing and handling the large volume of wood fuel that will be required to replace fossil fuels. Wood-fueled furnaces are less convenient and have more emissions than those operating on oil and natural gas. Finally, the use of pine-site hardwood chips as a fuel may have to compete with their use for making higher-value products.

CHAPTER 8

Economics

As a replacement for natural gas (at $2 per million Btu) to generate steam, pine-site hardwoods have a fuel value of about $15/green ton and when used to

Table 8-1.—*Fossil fuel cost for steam production and fuel replacement value for pine-site hardwoods*[1]

Fuel	Fuel cost[2]	Furnace efficiency	Steam cost	Fuel replacement value for pine-site hardwoods[3]
	$/MM Btu	*Percent*	*$/MM Btu*	*$/green ton*
Oil	2.20	80	2.75	15.73
Natural gas	2.00	76	2.63	15.04

[1] Does not include handling, storage, maintenance, amortization, or other costs.

[2] Representative values for natural gas and oil.

[3] Following assumed: 42 percent moisture content, higher heating value 7,827 Btu/lb, 63 percent furnace efficiency.

replace oil, the value is slightly higher (table 8-1). In other words, 1 green ton of pine-site hardwoods can be used to generate the same amount of steam as $15 worth of natural gas. If the wood costs less than $15, there is then a savings in fuel cost. The replacement fuel value for the pine-site hardwoods will, of course, continue to rise with the cost of oil and natural gas.

Fuel costs, however, are only one consideration in the total economic picture. Wood-fired boilers cost more and are more expensive to maintain than oil or gas-fired units. Koch and Mullen (1971) indicated that a steam boiler for burning bark and oil would cost about twice as much as a boiler using oil only. Similar cost comparisons have been noted by Corder (1973). Salo et al. (1978) estimated capital costs for installing new wood-fired steam boilers at about $13 million and $25 million for 155,000 and 387,000 lb/hr units. Annual operating and maintenance costs were projected at 1.4 and 2.8 million dollars. To retrofit an oil-fired boiler (1400 Bbl/day) to an 850 ovendry ton/day wood-fired unit would result in an additional capital investment of $21.5 million and an increase in annual operating and maintenance costs of $2.3 million, but would decrease fuel costs $4.2 million annually.

For the near future, the economics of changing to wood fuel will be site-specific. Pingrey and Waggoner (1978) and Salo et al. (1978) indicate there is general lack of economic incentive to change based on fuel savings alone. Salo et al. suggest an early retirement tax credit or an investment tax credit to encourage the use of wood as a fuel.

The economics of converting the pine-site hardwoods to other energy-related products is subject to considerable uncertainty because most of the conversion processes are not yet widely used. Additionally, costs of harvesting such hardwoods with conventional equipment are sometimes excessive. Several studies have been made to estimate the cost of converting wood into various energy forms, and the projected costs vary considerably. For example, the projected price of methanol from wood ranges from 40¢/gallon to 98¢/gallon. Such differences occur because different variables are used in the models to make the projections. The most obvious variables include feedstock cost, production plant size, and the amount of return on investment.

In a Mitre Corp. study, Salo et al. (1978) estimate the plant gate selling prices for various wood-derived energy products in order to assess the near-term potential (table 8-2). These values should be considered optimistic as feedstock costs are very low and a 10 percent rate of return was used on all products for comparison purposes. For the methanol, ammonia, and ethanol, this rate would probably be too low to be attractive to a private enterprise. The conclusion was that direct combustion of wood fuel is probably the best option for the forest products industry. The study indicated that a thorough gasification of wood to low Btu gas should be assessed to determine its potential for large-scale industrial applications such as pulp mills.

Table 8-2.—*Estimated "plant-gate" selling prices*[1] *for energy products derived from wood*[2] *($\$/10^6$ Btu heating value)*

	Plant size	
	850 dry tons/day	1700 dry tons/day
Process steam	2.70	
Low-Btu fuel gas	2.70	
Medium-Btu fuel gas	3.10	2.60
Charcoal without credits	4.90	4.60
Charcoal with steam credit	2.10	1.90
Subtitute natural gas	4.60	3.80
Ammonia	5.50 ($107/ton)	4.43 ($88/ton)
Methanol	7.60 ($0.50/gal)	6.20 ($0.40/gal)
Ethanol	20.40 (1.65/gal)	17.50 (1.40/gal)
Electricity	11.80 (40 mills/kWh)	8.80 (30 mills/kWh)

[1] Data from Salo et al (1978). Assumptions include a 10-percent return on investment after taxes.

[2] Wood cost is $\$1.00/10^6$ Btu.

Stanford Research Institute is preparing an economic report on wood energy processes likely to achieve commercialization by 1985 (table 8-3). (Schooley et al. 1978). The base case assumes feedstock cost of $30/dry ton while the optimistic case assumes $20/dry ton. The model assumes no subsidies or tax incentives and 15 percent return on investment.

In 1975 Katzen Associates reported on the separate or combined production of chemicals from wood (U.S. Forest Service 1976, Seaman[11] Grantham 1978, Hokanson and Rowell 1977). Table 8-4 summarizes data on the selling prices for a hardwood plant. Assumptions included a delivered price of $34/dry ton and that its availability is limited to 1,500 dry tons per day. Conclusions drawn from the Katzen report are that chemicals production from wood is not economically attractive.

CHAPTER 9

The Future

Wood fuel will play a major role in supplying increasing amounts of energy for the forest products through the turn of the century. However, the industry will probably depend on oil and natural gas for as long as these resources are available. Natural gas use is likely to continue for at least a decade. Coal is not a popular fuel alternative due to environmental considerations and the cost of shipping and handling, but its use will grow to perhaps 25 percent of the industry needs by 1985 (Junge 1975b). Wood residues will remain the best energy bargain, but economic use of wood sources such as pine-site hardwoods will depend on the development of adequate harvesting technology.

Oil and natural gas will continue to be the primary feedstocks for organic chemicals through the turn of the century and for as long thereafter as they remain the least expensive alternative (Krieger and Worthy 1978, Grantham 1978, Maisel 1978, Herrick and Hergert 1977). A popular view is to reduce the use of oil and natural gas for fuel and to reserve this source for petrochemical production. Before the 1940's, coal was the major source of organic chemicals and is considered the first alternative for both fuel and petrochemicals. At current energy consumption rates, there is enough coal to last several hundred years.

Wood will become more important as an industrial raw material because it is renewable. Demand for fibers for paper and textile products will more than double by the turn of the century (Jahn in press). While wood is not competitive with petroleum and coal for petrochemicals, it should be looked at for other specialized chemical products that take advantage of the unique molecular structure of wood and

Table 8-3.—*Sales prices required on 8 products to yield a satisfactory profit in large conversion facilities*[1]

Route	Conversion process[2]	Base case[3] (including feedstock at $30/dry ton)	Base case, (no feedstock cost[3]	Optimistic case[3] (including feedstock[4] at $20/dry ton)
		Dollars per million Btu		
Wood to:				
Heavy fuel oil	CL	5.37	3.47	4.76
Methanol	GOB	7.77 (0.50/gal)	6.01 (0.39/gal)	6.72 (0.44/gal)
Ammonia ($/short ton)	GOB	164.00	126.00	141.00
Substitute natural gas	GOB	6.41	4.80	5.56
Steam	DC	3.00	1.68	2.73
Electricity	DC	16.38	11.62	14.40
Steam and electricity	DC	3.42	2.09	3.06
Oil and char	P	4.50	1.40	4.00

[1] Data from Schooley et al. (1978).

[2] Key: CL = catalytic liquefaction
GOB = gasification—oxygen blown
DC = direct combustion
P = pyrolysis

[3] 1977 dollars in year 1985. Sales values tabulated will return yield calculated to yield a 15-percent discounted cash flow rate of return on equity and a 9-percent rate of return on debt.

[4] Capital cost = 80 percent of base case.

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[11] J. F. Saeman. Energy and materials from the forest biomass. 20 p. Paper presented at Institute of Gas Technology Symp. on Clean Fuels from Biomass and Wastes. (Orlando, Fla., Jan. 25-28, 1977).

Table 8-4.—*Estimated selling prices for chemicals from single-product and multiproduct hardwood plant*[1]

Type of plant	Product output	Plant size	Selling price[2]	1975 market price
		Dry tons/day		
Single-product plant				
Methanol	50 x 10^6 gal/yr	1,500	$0.98/gal	$0.38/gal
Ethanol	25 x 10^6 gal/yr	1,480	$1.90/gal	$1.04/gal
Furfural	40 x 10^6lb/yr	760	$0.61/lb	$0.37/lb
Multiproduct plant[3]				
Ethanol	25 x 10^6 gal/yr	1,500	$1.28/gal	$1.04/gal

[1] Data from J. F. Saeman. Energy and materials from the forest biomass. 20 p. Paper presented at Institute of Gas Technology Symp. on Clean Fuels from Biomass and Wastes. (Orlando, Fla., Jan. 25-28, 1977).

[2] Selling price based on an annual depreciation of investment of 8 percent and profit of 15 percent (after Federal taxes).

[3] Selling price assumes a credit for furfural and phenol at 65 percent of market selling price.

bark. For better chemical utilization of wood, research should focus on making the ligno-cellulosic complex accessible to chemical and biological action, increased use of cellulose and lignin as polymers, producing specialized chemicals, and catalyst research and development.

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A Survey of Timber Harvesting Simulation Models for Use in the South

DANIEL V. GOULET, DONALD L. SIROIS,
AND RONALD H. IFF

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SUMMARY

Nine forest harvesting simulation models with potential for simulating southern operations are reviewed in detail. An annotated bibliography of associated forest harvesting simulation literature is appended. From the nine models, five appear useful enough to warrant further analysis. They are: 1. Forest Harvesting Simulation Model (FHSM) developed at Auburn University; 2. Full-Tree Field Chipping and Transport Simulator (FTFC) developed at USDA Forest Service North Central Forest Experiment Station; 3. Harvesting System Simulator (HSS) developed by the American Pulpwood Association; 4. Simulation Applied to Logging System (SAPLOS) developed at the USDA Forest Service northeastern Forest Experiment Station; 5. Timber Harvesting and Transport Simulator (THATS) developed at the USDA Forest Service Northeastern Forest Experiment Station.

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INTRODUCTION

The Southern States produce 45 percent of the total roundwood harvested in the United States. This percentage is expected to grow to 50 percent by the year 2000. During the same period, 4 million acres of commercial forest lands will be lost to other uses. So, much further production will have to come from poor or fragile sites and from small tracts, sites that cannot now be productively managed unless alternative harvesting systems are developed. The possible interrelationships among production, cost, and energy usage for both present and future harvesting systems need to be evaluated. Computer simulation is one possible evaluation strategy. A systems simulation model for the southern harvesting operations would assist in this analysis.

As a first step in using simulation for analysis of southern harvesting systems, we conducted a literature survey to identify existing models, to determine their stage of development, and to evaluate their capability for modeling southern operations.

We found that many timber harvesting simulation models have been developed in North America in the last 10 to 15 years. Some of the models are complete systems models (2, 3, 6, 8, 10, 11,13, 16, 18, 21, 23, 25, 26). Others model particular phases of the harvesting operation (1, 4, 7, 12, 20, 24). Some models are fully developed (6, 9, 11, 13, 16, 18, 23, 25), while others are being refined (3, 22). Though most models have been developed for conditions outside the South, we found nine systems-simulation models that showed potential for modeling southern harvesting operations, and they are reviewed here. Many other models that focus on machine or other related simulation were also found. These models are documented in the appendix.

SYSTEMS MODELS

Auburn Pulpwood Harvesting System Simulator

The Auburn Pulpwood Harvesting System Simulator (APHSS) is a FORTRAN-based, time-oriented simulation of southeastern pulpwood harvesting systems. The model was developed by William H. Bussell, James N. Hool, Alfred M. Leppert, and Grady Harmon, all of Auburn University, Auburn, Alabama. The model, as expanded and refined by Robert Osborn, is available through Hool. Both development and refinement were sponsored by the Southern Executives Association.

Bussell et al. (8) document the design parameter of APHSS and divide the harvesting operation into a production phase and a transportation phase. Only the production phase, which consists of felling, limbing and topping, skidding, bucking, bunching, and

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loading, is simulated. Interactions between operations are modeled with the use of buffer inventories. Average cycle times on each operation are used, making the model deterministic. A uniform time increment advances the simulated clock, with simulation variables updated at each time increment. Three reports are generated: end of hour, end of day, and end of week, the latter two involving a cost-per-log-produced statement as well as production.

Bussell et al. (9) document the usefulness of APHSS by placing observed average operating times into the model and adjusting the system configuration for maximum wood production. One system is extensively studied and reported.

Osborn (23) modified APHSS to simulate a variety of pulpwood harvesting systems and added a transportation phase to the model (fig. 1). Critical assumptions and restrictions are as follows:

1. An unlimited number of trees are available for felling.
2. All trees are the same size.
3. All systems components of the same type create a common inventory.
4. Each component is confined to a particular function.
5. Each component in a system operates independently.
6. All system irregularities are reflected in cycle times.
7. All configurations are limited to a maximum of six components (excluding transportation).
8. All component cycle times must be evenly divisible by the specified uniform time increment.

Three example systems are simulated.

	CONFIGURATION													
COMPONENTS	SHORTWOOD								LONGWOOD					
FELLING	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LIMBING	X	X	X	X					X	X	X			
SKIDDING	X	X			X	X			X	X		X	X	
BUCKING	X	X	X	X	X		X	X						
BUNCHING	X		X		X	X	X		X		X	X		X
LOADING	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TRANSPORTATION	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Figure 1.—Configurations of the Osborn Modified APHSS model.

Forest Harvesting Simulation Model

The Forest Harvesting Simulation Model (FHSM) is a general, event-oriented timber and pulpwood harvesting simulator developed by Dennis B. Webster and expanded and refined by John R. Killham, both of Auburn University. The model is modular in that functional elements, felling, limbing,etc., act as building blocks and can be arranged in various combinations. Consequently, the model can be tailored to the specific harvesting operations. The model, available through Webster, is written in FORTRAN and uses GASP II for its executive control.

Webster (26) details the following design parameters for simulating the major types of saw-log and pulpwood-harvesting operations in the South.

a. The simulator should be flexible enough to duplicate the major harvesting operations used in timber-harvesting systems in the South.
b. The model should be detailed enough to allow for possible analyses of individual harvesting operations.
c. The model should possess a high degree of believability in the way it duplicates a system's operation.

To satisfy the first design parameter, FHSM simulates the functional elements of various harvesting operations, such as felling, limbing, etc. The model for a particular system, a configuration in Webster's terms, can be assembled by collecting the functional elements that constitute the operation.

To satisfy the second design parameter, each functional element allows different pieces of equipment to perform the same task while differentiating each piece's characteristics and capabilities. For example, two different skidders in the skidding phase could be used.

To satisfy the third design parameter, wood flow in the model matches the actual wood flow in a harvesting operation. A tree or its parts are maintained as identifiable units from selection for felling until deposition at the mill. We call this wood flow property "continuous across processes." Webster uses two configurations as pilot demonstrations of the model's capabilities.

Killham (16) expanded Webster's basic design and pilot system into a working model. He considers ten timber harvesting configurations, six for sawtimber and four for pulpwood. Each configuration in FHSM is a combination of some of all eight basic harvesting processes—felling, limbing, bucking at the stump, skidding, bucking at the landing, loading, hauling, and unloading, and is identified in figure 2.

OPERATIONS	CONFIGURATION									
	SAWTIMBER						PULPWOOD			
FELLING	X				X	X	X	X		
LIMBING	X				X	X	X	X		
FELLING & LIMBING		X	X	X					X	X
BUCKING AT THE STUMP	X	X					X		X	
SKIDDING	X	X	X	X	X	X		X		X
BUCKING AT THE LANDING			X			X		X		X
LOADING	X	X	X	X	X	X	X	X	X	X
HAULING	X	X	X	X	X	X	X	X	X	X
UNLOADING	X	X	X	X	X	X	X	X	X	X

Figure 2.—Configuration of FHSM.

The configuration acts both as an operations design or tailoring parameter, and as a simulation's run-time control parameter, which identifies the subroutines in the computer program to be used. Hence, both the design and the execution of the model are modular, that is, only those building blocks that identify the configuration are used. The working model allows for a unique description of the operating characteristics for each man and machine unit involved in harvesting operation. These characteristics are averages or empirical distributions collected from time and motion studies, so there is complete flexibility in determining the harvesting elements within the model. For example, fellers with chain saws and mechanical shears can be operating together. Operating statistics in terms of production units and time are collected on each man and machine unit modeled. The specification of individual man and machine units and the collection of operating statistics on these same units permit a detailed analysis of individual harvesting operations.

The forest data and the continuous wood flow give the model a high degree of believability. The forest data are generated from a standard timber cruise, and consist of total number of trees to be harvested, average spacing between trees, percentage of total that is pine, diameter class distributions, merchantable height distributions, and defect distributions for sawtimber logs. Continuous wood flow maintains that the output in terms of pieces (trees or parts) from one process (e.g. felling) is the input for the next process (e.g. limbing).

The output reports are in terms of production units, (e.g. number of trees felled, total board feet delivered to the mill) and processing times. The model contains no economic analysis.

Full-Tree Chipping and Transport Simulator

The Full-Tree Chipping and Transport Simulator (FTFC) is a package of two GPSS/360 simulation models, one for chipping and one for transport, designed to simulate in-woods full-tree chipping. The models were developed by Dennis P. Bradley, Frank E. Biltonen, and Sharon A. Winsauer, of the USDA Forest Service North Central Forest Experiment Station, St. Paul, Minnesota, and are available from the Station.

Bradley et al. (6) describe a simulation that both models the activities of feller-bunchers, skidders, a chipper, trucks and vans in the field, and models dumping and scaling at the mill. The stand to be harvested must be provided by the user in the form of (x,y) coordinate location of trees, volume of each tree in the stand, and felling order for the feller-buncher. The model keeps individual tree identity until the tree is chipped and blown into the van. Machine interactions have been carefully considered so that one skidder can "see" another in the woods and will not interfere with it. Start-up and shut-down conditions for each day can be specified.

Three trucking situations are modeled in the transport segment:

Situation 1.
  a. There are no terrain and road problems; highway tractors with vans can drive directly to the chipper without assistance.
  b. Setout trucks for handling empty and full vans are not required, because either
    (1) there are no extra vans, or
    (2) there are extra vans but the number of slots at the chipper equals or exceeds the total number of vans.

Situation 2.
  a. There are still no terrain or road problems; highway tractors can get

to the chipper without assistance, but

b. One or more setout trucks are required some of the time because both of the following conditions are true:
   (1) there are extra vans and
   (2) the number of slots at the chipper is less than the total number of vans.

Situation 3.

a. Terrain and/or road problems prohibit the highway trucks from bringing empty vans to the chipper. They must drop empties and pickup full vans a considerable distance away.
b. One or more setout trucks must therefore do all the work of moving empty and full vans to and from the chipper. Setout trucks in this situation are probably specially modified dozers or skidders with a fifth wheel.

The model's report generator provides detailed production and cost statistics by operation, system energy consumption, and net energy produced, the latter two in the form of BTU's.

Bradley and Winsauer (7) focus on the last stage of a harvesting operation, chipping and hauling to the mill. Their model attempts to determine the optimal combination of men, trucks, vans, and operating rules for the observed chipping rate. Their model has five segments: 1) chipper, 2) trucks and vans, 3) setout trucks, 4) a mill yard, and 5) records. Wood is assumed to be presented to the chipper by a "black box" operation that allows the chipper to fill vans at a variable rate. The model's report generator produces a statement of the system characteristics and production, and cost statistics. Two examples, one a case study and one a hypothetical case, are presented.

The Georgia Tech Model

The Georgia Tech model is the first result of a research grant awarded in 1967 by the Southern Executives Association to Georgia Institute of Technology to study the systems aspects for pulpwood harvesting and transportation. The research requirements were to structure a systems model that validly represents the significant characteristics of and constraints on present systems, and on systems that may appear up to the year 2000. The GPSS model, developed by Stark (25), is one of the earliest attempts at simulating the forest harvesting system. Strong emphasis in his work was placed on production of 5'3" pulpwood in the South. Twenty-eight different harvesting configurations, which represent the small pulpwood producer's operations, are modeled (figs. 3, 4).

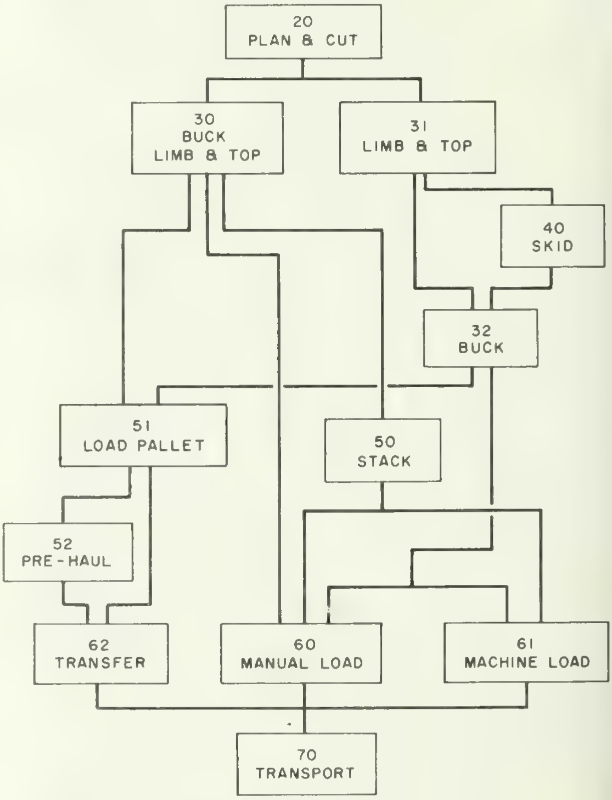

Figure 3.—A flow diagram of basic 6'3" pulpwood harvesting operations.

The Harvesting System Simulator

The Harvesting System Simulator (HSS) is a FORTRAN-based simulation program designed to simulate the productive and nonproductive activities (down time, breaks, etc.) of a harvesting system. The model was developed by the American Pulpwood Association during the late 1960's and early 1970's under their Harvesting Research Project. In 1974 APA

ystem No.	Harvesting Operation Number Sequence							
1.	20	31	32	51	52	62	70	
2.	20	40	31	32	51	52	62	70
3.	20	31	40	32	51	52	62	70
4.	20	30	51	52	62	70		
5.	20	40	30	51	52	62	70	
6.	20	31	32	51	62	70		
7.	20	40	31	32	51	62	70	
8.	20	31	40	32	51	62	70	
9.	20	30	51	62	70			
10.	20	40	30	51	62	70		
11.	20	31	32	61	70			
12.	20	40	31	32	61	70		
13.	20	31	40	32	61	70		
14.	20	30	50	61	70			
15.	20	40	30	50	61	70		
16.	20	31	32	50	61	70		
17.	20	40	31	32	50	61	70	
18.	20	31	40	32	50	61	70	
19.	20	31	32	60	70			
20.	20	40	31	32	60	70		
21.	20	31	40	32	60	70		
22.	20	30	60	70				
23.	20	40	32	60	70			
24.	20	32	50	60	70			
25.	20	40	32	50	60	70		
26.	20	31	32	50	60	70		
27.	20	40	31	32	50	60	70	
28.	20	31	40	32	50	60	70	

igure 4.— Possible combinations of harvesting operations in the Georgia Tech model.

eleased HSS to Virginia Polytechnic Institute nd State University, Blacksburg, Virginia, here it remains.

The American Pulpwood Association's User uide (2), though somewhat out-of-date relative o format and input characteristics, provided a ood description of the workings of HSS from he user's point of view.[1] It details the kinds of nputs necessary, defines these, and states their nterrelationships. The three parts of the rogram package (the simulator, the two report enerating programs-production and perations report, and the cost analysis report) re explained.

O'Hearn (21) describes the current status of HSS. A maximum of 14 machines, working in any combination, and a maximum of six aggregations of like machines (phase) can be simulated. The harvested tract can be divided into a maximum of 14 harvesting areas that can differ in stand type, volume per acre, species composition, and skidding distance to the primary landing. Individual harvesting areas have no acreage or volume limits. Unique production rates may be specified for each harvesting area-machine combination. The user controls the order in which harvesting areas are processed. Terrain and stand limitations are modeled through move or travel rate modifiers and deck locations. Wood flows from phase to phase in aggregated volumes.

Nonproductive activities, such as machine failures, breakdowns, delays, and servicing, can be imposed logically or stochastically. Repairs can be made at the stump, the deck, or the shop. Repairs at the stump hold the machine in place, while repairs at the deck or shop require the machine to move to the primary deck. Delays are divided into two types major and minor. Major delays bring the machine back to the deck, while minor delays leave it in place. A distribution between productive and nonproductive time can be provided.

Program output is provided by two report generators that can be called on separately or jointly. They provide time, production, cost, and revenue statistics. Also, discounted cash flow and return on investment analysis can be made. All output reports are detailed and complete.

A Method for Analyzing Environmental Effects of Impacting Activities.

A Method for Analyzing Environmental Effects of Impacting Activities, a FORTRAN/GASP IV model, simulates, in two phases, the effect of an impacting activity on the ecosystem (11). Phase one, the impacting activity, is modeled in the microphase and can be used by itself for detailed study of the activity. The three impacting activities modeled are timber harvesting, road building, and fire. For timber harvesting, SAPLOS[2] is used. Phase two, the ecosystem, is modeled in the

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new User Guide is nearing completion under the direction f W.B. Stuart, VPI & SU, Blackburg, Va.

[2] SAPLOS is documented later in the report as a separate model and will not be repeated here.

macrophase and simulates the dynamic response of the ecosystem to the impacting activity. The six subsystems that model the ecosystem are area, moisture-water, timber, forage, wildlife, and erosion. The model was developed by Louis T. Egging at Montana State University, Bozeman, Montana, and is available from him.

Residues for Power

Residues for Power (REPO), a SIMCOMP[3] model, evaluates systems for handling logging residues for fuel. The model was developed by B. Bruce Bare, Benjamin A. Jayne, and Brian F. Anholt, at the USDA Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, and is available from the Station.

Bare et al. (3) report the basic objective is to simulate the transfer of harvesting residues, in the form of chips, to a hypothetical power plant. Various combinations of skidding, loading, transporting, unloading, sorting, and chipping are examined (the exact combinations are not documented). Rate functions, for example volume per unit time, govern the materials flow from operation to operation. Stores of materials between operations model the materials in process and the influence of one operation upon another.

REPO is a fixed time increment model with a 9-hour workday as the unit of measure. Tracking of activities within one workday is not possible, nor can the model account for machine interactions within this time period. However, the serial nature of the operations will not allow following operations to be simulated until all preceding operations have been completed.

Though developed as a residue handling model, REPO is actually a more general materials handling model that can be used to simulate a timber harvesting and transportation system.

Simulation Applied to Logging Systems

Simulation Applied to Logging Systems (SAPLOS) is a general logging simulation model adaptable to a variety of logging configurations. Begun in 1971 in a FORTRAN and GASP II version, it has been changed to a FORTRAN model with GASP IV providing executive control of the simulation. The model was developed by Leonard R. Johnson, Donald L. Gochenour, Jr., and Cleveland J. Biller at the USDA Forest Service Northeastern Forest Experiment Station, Morgantown, West Virginia, and is available from the Station.

Johnson's model (12), a precursor of SAPLOS, is a FORTRAN and GASP II simulation of the materials handling problem involved in the loading and hauling phases of a timber harvesting operation. Johnson's objective is to produce a cost estimate, in terms of equivalent annual costs, by which different loading and hauling systems can be compared. The material handling operations are simulated, and production statistics are gathered. From these, and machine operating cost data, an equivalent annual cost is computed. Both the production statistics and equivalent annual costs are documented in the report generator.

Johnson et al. (15) document the first work on SAPLOS and identify the model's design parameters. SAPLOS' development progressed through three phases of work: 1) identifying and classifying the prevelant logging system configurations in Appalachia and their interaction points, 2) within a subsystems general operation, determining the sequence of activities defining the operation, 3) combining activities of the subsystems into events in the computer model. In the first phase, Johnson et al. found that Appalachian logging systems predominately involve felling, skidding, loading, and hauling; some systems may include bucking and pre-bunching. These six subsystems represent the standard operations for SAPLOS. Felling and bucking are the production functions of the logging systems, while skidding, loading, hauling and prebunching are considered material-handling operations. When the events of two logging operations overlap, a point of possible interference occurs. These points are considered "critical locations" on the ground and form control points in the model, signaling the beginning and ending of model activities. The nodel is written in FORTRAN with GASP II roviding control of the simulation.

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[3] The SIMCOMP programming language is a machine-dependent simulation language written at Colorado State University for the CDC 6400 computer. The language is designed for compartment-oriented simulation models. Programming in SIMCOMP requires an understanding of the FORTRAN IV language, since the SIMCOMP compiler creates a FORTRAN program which is compiled by the CDC Extended FORTRAN compiler.

Biller et al. (5) use SAPLOS to compare three lifferent systems logging the same site under dentical stand conditions. The systems are:

1. A ground system with a crew of three. The operation is comprised of a feller who uses a chain saw and doubles as a choker setter; a wheeled skidder operator; and an operator of a self-loading, trailer truck.
2. A ground system with a crew of seven. One man fells with a chain saw. For skidding there are two skidder operators and two choker setters. Two self-loading trucks are used for hauling.
3. A skyline system with a crew of eight. The skyline yarder operator and a rigging boss perform the skidding operation along with two choker setters and a chaser. The other three men, a sawyer and two truck drivers, perform as in the second system.

Johnson and Biller (14) add the in-woods, full-ree chipping operation to SAPLOS. Three situations for an in-woods, full-tree chipping peration are presented. Each is then balanced, vith time and cost per cubic foot of chips roduced as the balancing criteria. The objec-ive of this demonstration is to show how simulation can be used as a tool for the manager n setting up in-woods, chipping operations.

Johnson (13) presents SAPLOS' final version, vhich follows the design parameters specified n (15). In the design five critical locations are dentified where logging operations can interact and are modeled as the key division points. The activities necessary to deliver logs to these oints are modeled by identifying equipment and end of service events at each location. The esulting model can simulate logging systems varying from small pulpwood crews to west oast skyline operations to in-woods chipping ystems.

Specifically, the different configurations of ogging operations possible can be summarized y listing the activities modeled at each critical ocation, and putting them together in various ombinations. The activities are:

(1)	Felling:	Manual tree length Manual with bucking in the woods Mechanical (shears)
(2)	Bucking:	In woods by feller At landing Haul tree length (no bucking)
(3)	Skidding:	Prebunching logs to skid road Ground skid from woods or road to landing Cable yarding
(4)	Loading:	Separate loading unit Loader mounted on hauling unit Whole tree chipping
(5)	Hauling:	Straight haul to mill Prehaul to docking area

To run the model, the user must write two system specific subroutines, TRESZ (tree size) and DISTM (distance and time). TRESZ is used to find or generate tree volumes, diameters, and lengths. The tree parameters are generated by: 1) determining a butt diameter, 2) based on the butt diameter, producing a merchantable tree height, and 3) then calculating the tree volume as a function of butt diameter and height. The resulting parameters should depict the stand to be harvested. TRESZ is called and a tree is produced as needed.

Any time a distance or a production time is needed, DISTM is called and the necessary item is generated. The distance and time generators reflect the stand and operating conditions of the logging operations being simulated.

The report generator gives detailed production and cost statements by activities and for the process as a whole.

Timber Harvesting and Transport Simulator.

The FORTRAN-based Timber Harvesting and Transport Simulator (THATS) simulates the standard harvesting configuration of felling-limbing-topping, bunching, skidding, bucking, loading, and hauling. THATS was developed by A. Jeff Martin at the USDA Forest Service Laboratories in Princeton and Morgantown, West Virginia, and is available from Martin upon request.

Martin (17) examines the potential of computer simulation as a tool for forest management work. He presents a harvesting operation analysis that includes costs, production, balance, and a sensitivity analysis on the number of elements (e.g. fellers) in the production components.

Martin (18) describes the structures, methodology, and main components of THATS. THATS is built around a main program composed of eight components (felling, bunching, skidding, bucking, loading, hauling, roadbuilding, and cost accounting) and a "clock." The model is a time oriented simulation in which simulated time on the clock is advanced one minute, then checks are made for active events.

Simulated event times are generated either from given averages and standard deviations, or from event times produced by a regression equation developed from collected data. All random variable event times have either a normal or a log normal distribution. If any skewing is present in the time study data, the log normal distribution is used. Regression equations from data collected for Appalachian logging operations are contained in the report.

The system simulates one day at a time and shuts down at the end of the working day in a staggered manner, with each crew finishing the day close to quitting time, though depending on the task at hand, some may be a little early and some may be a little late.

Wood flows through the model in a volumetric manner. The input to an operation is a tree or a piece of a tree, and the output from the operation is a volume. The next operation draws trees or pieces from the deposited output volume, but these new trees or pieces have no relation to the input trees of the first operation except that their total volume equals the deposited output volume. For example, a tree is generated for the felling operation, felling statistics are collected on that tree, and the volume of that tree is deposited for the bunching operation. The bunching operation will now generate new trees up to the volume of the felled trees deposited.

A User's Guide for THATS, Martin (19), contains a detailed description of each input

CHARACTERISTIC MODEL	GENERAL PARAMETERS LANGUAGE	CONTINUITY ACROSS PROCESSES	FLEXIBILITY:	PULPWOOD	SAWTIMBER	CHIPPING	PLYWOOD	INPUTS:	OPERATING COSTS	OPERATING TIME	CAPACITIES	LONG RUN COSTS	STAND PARAMETERS:	(X, Y) TREE LOCATION	TREE VOLUME	DBH	MERCHANTIBLE HEIGHT	TREE DENSITY	TOTAL NUMBER OF TREES HARVESTED	SPECIES	AREA TO BE HARVESTED	SLOPE	TERRAIN	OUTPUTS:	PRODUCTION (AMOUNTS)	PRODUCTION TIMES	ECONOMIC	DELAYS:	SCHEDULED (LUNCH, etc)	LOGICAL (SYSTEM)	STOCHASTIC (BREAKDOWNS, etc.)	SPECIAL PROBLEMS CONSIDERED:	ENVIRONMENTAL	RESIDUE PROCESSING	TRANSPORTATION	ROAD BUILDING	DAILY START UP & SHUT DOWN CONDITIONS	INTERACTIONS WITH BUFFER INVENTORIES
APHSS	FORTRAN	X		X	X				X	X	X				X		X								X	X	X		O	X	O							X
FHSM	GASP II	X		X	X					X	X					X		X	X	X					X	X			O	X	O							X
FTFC	GPSS	X		X		X			X	X	X			X	X	X	X	X			X				X	X	X		O	X	O				X		X	
GEORGIA TECH	GPSS	X		X						X	X					X		X	X			X	X		X													X
HSS	FORTRAN	O		X	X	X	X		X	X	X	X			X			X	X		X		X		X	X	X		X	X	X						X	X
EGGING'S	GASP IV	O		X	X	X	X		X	X	X	X		X	X	X	X		X		X	X			X	X	X		X	X	X		X				X	
REPO	SIMCOMP	X				X			X	X	X				X				X		X	X			X	X	X		X	X	X			X		X	X	X
SAPLOS	GASP IV	O		X	X	X	X		X	X	X	X		X	X	X	X		X		X	X			X	X	X		X	X	X						X	
THATS	FORTRAN	O		X	X				X	X	X				X	X	X		X						X	X	X		X	X	X					X	X	X

KEY

X – CONSIDERED IN MODEL
BLANK – NOT APPLICABLE FOR MODEL
O – SHOULD BE CONSIDERED
A – USES AN AVERAGE
D – USES A DISTRIBUTION
D⟶ – ONE DISTRIBUTION SPANS THE ACTIVITIES
A⟶ – ONE AVERAGE SPANS THE ACTIVITIES

Figure 5.—Comparison of system simulation models.

ieeded to run THATS, a random number enerating routine, a list of all variables used, nd a source listing of the complete THATS ode.

COMPARISON OF SYSTEMS MODELS

The nine models examined are compared and ontrasted in figure 5. The first result evident rom examining figure 5 is that no consensus xists on what constitutes the essential lements of a forest harvesting model. Forest lata, for example, run the complete gamut from ll trees being of a single volume and merchanable height (APHSS) to trees located by (x,y) oordinates, and given a d.b.h., merchantable ieight, and volume (SAPLOS). Some models ddress a single harvesting system (pulpwood n the Georgia Tech Model), and others have a nultiplicity of systems (SAPLOS, HSS, FHSM).

The second item of major importance reflected n figure 5 is that there is great variety in the detail simulated in the models. This variety reflects the point of view of the modeler and must be given careful consideration when selecting a model for use. Timber flow, for example, occurs in essentially two ways: (1) a tree is harvested, its volume determined and deposited in an inprocess volume pool, and the identity of the tree is lost, (HSS, Egging's, SAPLOS, THATS); (2) tree parts maintain their identity and characteristics from stump to mill (FHSM, Georgia Tech, FTFC).

Lastly, input requirements and output information can only be given in gross terms. For example, although all models use "operating time" as an input, precisely what kind of operating time (average, distribution, regression equation) is not identified. A similar statement could be made for the output parameter "production amounts." Consequently, each model needs to be examined for its input/output characteristics.

CHARACTERISTIC / MODEL	OPERATIONAL PROCESS	FELLING:	TRAVEL TIME/SPEED TO TREE	FELLING TIME	EQUIPMENT:	CHAIN SAW	SHEAR	GENERAL	LIMBING-TOPPING:	TRAVEL TIME/SPEED TO TREE	LIMBING TIME	EQUIPMENT:	CHAIN SAW	GENERAL	BUCKING:	TRAVEL TIME/SPEED TO TREE	BUCKING TIME	DEFECTS CONSIDERED	EQUIPMENT:	CHAIN SAW	GENERAL	BUNCHING:	TRAVEL TIME/SPEED TO TREE	BUNCH ACQUISITION TIME/SPEED	TRAVEL TIME/SPEED TO DROP	DROP TIME/SPEED	BUNCH VOLUME LIMIT	BUNCH STEM LIMIT	EQUIPMENT:	MECHANICAL	MANUAL	GENERAL
APHSS				A		X				A→	→		X				A			X			A→	→	→	→				X		
FHSM			A	A				X		A	D			X		A	D	X		X		O										
FTFC			D	D			X																				X	X				
GEORGIA TECH			D	D				X			D			X			D			X			A→	→	→	→				X	X	
HSS			D	D				X		D	D			X		D	D				X		D	D	D	D						X
EGGING'S				D		X	X		X*								D				X		D	D	D	D				X		
REPO																																
SAPLOS				D		X	X		X*								D				X		D	D	D	D				X		
THATS			A	D				X			D			X			D			X				D								

* INCLUDES WITH FELLING

Figure 5.—Comparison of system simulation models—Continued.

CHARACTERISTIC / MODEL	SKIDDING:	CHOKE TIME/SPEED	INHAUL TIME/SPEED	UNCHOKE TIME/SPEED	OUTHAUL TIME/SPEED	WEIGHT LIMIT	VOLUME LIMIT	STEM LIMIT	EQUIPMENT:	SKIDDERS	SKYLINE	LOADING:	GRAB TIME/SPEED	SWING TIME/SPEED	DROP TIME/SPEED	LOADER REPOSITION TIME/SPEED	TRUCK REPOSITION TIME/SPEED	SORTING TIME	HAULING:	TRACTOR/TRAILOR/VAN POSITIONING TIME	HOOK UP TIME	UNIMPROVED ROAD HAULING TIME/SPEED	IMPROVED ROAD HAULING TIME/SPEED	SCALING TIME	UNLOADING TIME	RETURN TIME/SPEED	UN-HOOKING TIME	EQUIPMENT:	CHIP VANS	TRACTOR TRAILORS	BOBTAIL TRUCKS
APHSS		A→	→	O	A			X		X			A→	→	→	→				A→	→	→	→	→	→	→				X	
FHSM		A	D	A	D	X				X			D→	→	→	A	A	A		A		A	A	D	D	A				X	X
FTFC		D	D	D	D		X	X		X			D	D	D	D				D	D	D	D	D	D	D	D		X		
GEORGIA TECH		D→	→	→	→		X			X			D→	→	→	→						D	D		D					X	X
HSS		D	D	D	D					X			D→	→	→	D						D	D			D			X	X	X
EGGING'S		D	D	D	D		X	X		X	X		D→	→	→						D	D	D				D		X	X	X
REPO		D	D	D	D			X		X	X		D→	→	→			D				D	D		D	D			X	X	
SAPLOS		D	D	D	D		X	X		X	X		D→	→	→						D	D	D				D		X	X	X
THATS		D	D	D	D		X			X			D→	→	→		D					D→	→		D	D				X	X

Figure 5.—Comparison of system simulation models—Continued.

SELECTION OF PRIMARY MODELS FOR FURTHER STUDY

After examining the literature and comparing the properties of each model, we removed APHSS, the Georgia Tech Model, Egging's model, and REPO from further consideration. APHSS is a deterministic model that uses only averages for operational parameters, and hence cannot model the stochastic nature of the harvesting operation. The Georgia Tech Model, though the first step in a complete systems analysis, is outdated and needs to be redeveloped for today's systems. Egging's model, though it contains some interesting environmental modeling, uses SAPLOS for the timber harvesting portion, so the portion of interest in this search is contained in SAPLOS and can be studied there. REPO is claimed to be a general materials handling model built around the idea of simulating the residue handling process, but converting the model into a harvesting systems model would require much additional work. Also, the model is written in a machine dependent computer language that makes using it on other computers difficult.

The remaining five models have the best potential for modeling most of the southern operations with provisions for expansion to additional configurations not included now. No model, either completed or planned, contains all southern forest harvesting operations. The potentials of these five models are:

1. FHSM is specifically designed to model the southern operations. Though incomplete, the model has the basic structure for an accurate and realistic description of the harvesting operations. The modularity of design makes additions and modifications to the model relatively straightforward.
2. FTFC represents the only complete analysis of in-woods, full-tree chipping. HSS and SAPLOS each contain a chipping configuration, but neither is as detailed as Bradley's model.
3. HSS is the most detailed of all the models examined. Most of the southern

harvesting operations have been considered. The interaction of events has been modeled carefully. Production, delay, and cost reports permit analysis of the harvesting operation from many different points of view.

4. SAPLOS is a generalized harvesting simulation model adaptable to a variety of logging situations. The model contains most southern harvesting operations.
5. THATS, though limited to a single harvesting configuration, is a complete analysis of that configuration for the Appalachian region. Also, the model contains a roadbuilding operation not found in the other primary models.

Published literature does not contain sufcient information to assess each model fully. /e have initiated a follow up study to provide an 1 depth analysis of each model's strengths, eaknesses, computer codes, input data reuirements, output data information, and apabilities for modeling the southern perations.

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APPENDIX

ASSOCIATED HARVESTING SIMULATION LITERATURE

Almquist, Anders.
1968. A simulation model for feller-bunchers, Ekonomi 7 Forskningsstiftelsen Skogsarbeten (Logging Research Foundation), Stockholm, Sweden, 4 p.

The feller-buncher model—which consists of two parts, a stand model and a machine model—is Newnham's (1967a) model modified for Swedish conditions. The machine is made to operate in the stand generated by the stand model. The manner in which the feller-buncher proceeds through the stand is governed by a set of decision rules that make it independent of the modeler. The model tests machine characteristics and harvesting strategy, but cannot take different terrain features into consideration.

Bertils, Bertel Randolph.
1969. A GPSS II model to evaluate terrain

capabilities of typical pulpwood harvesting vehicles, M.S. Thesis, Ga. Inst. of Tech., Atlanta. 95 p.

This thesis proposes to pulpwood producers a means to evaluate, before purchase, how well typical pulpwood harvesting transport vehicles perform in various terrain conditions. The model uses the physical and operational characteristics of the vehicle as input parameters and "traverses it" across five typical terrain types found in the Georgia pulpwood harvesting areas. The vehicle is evaluated under four conditions in each terrain type: (1) soft soil mobility, (2) stability with respect to slope and soil microgeometry, (3) vegetation obstacles, and (4) terrain obstacles of, or caused by, hydrology.

Bertils conducted two experiments to give the pulpwood producer a measure of the effectiveness of each machine in each terrain type. The first experiment determines with a probability, the percentage of resource areas the producer could harvest before his vehicle is overcome by terrain obstacles. The second determines if tire size causes differences in vehicles performance.

Corcoran, Thomas J.
1971. Timber harvesting system design and equipment leveling through GPSS/360. Trans. of ASAE, 14:248-252.

Corcoran advocates GPSS as a tool for rigorous planning in timber harvesting systems. Models in GPSS can be made modular so that each machine is a miniature simulation. He also believes the language is ideally suited for those who have the most knowledge of the actual system to be simulated. Thus, the model may be created mostly by professionals in subject-matter fields that relate to the technical features of the system and not necessarily by specialist computer programmers.

Newman, Lawrence C.
1975. Direct loading with the Koehring harvester—a simulation model. For. Manage. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-83. 3 p.

The purpose of Newman's FORTRAN simulation is to see if a change in the use of Koehring harvesters from stockpiling to direct loading onto hauling vehicles would reduce cost of pulpwood delivered to the mill.

Newnham, R. M.
1967a. A progress report on the simulation model for pulpwood harvesting machines. For. Manage. Res. and Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-6. 41 p.

A simulation model for a feller-buncher passing through a pulpwood stand is presented. Stand and machine characteristics are the input parameters. Outputs break down the harvesting time into traveling, felling and bunching, unloading and non-productive. The position of each sweep and the number of trees and volume felled in each sweep are also produced.

The model is designed to help cut time and costs spent developing and testing prototype feller-bunchers. The initial machines simulated are of the Beloit type tree harvester and LRA feller-bunchers. Because these machine types have a swing boom with an attached shear, the machine passes through the stand in a straight line.

Newnham, R. M.
1967b. A FORTRAN programme to simulate pulpwood harvesting machines. For. Manage. Res. and Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-7, August. 32 p.

This report describes the FORTRAN program and its use for the above model, (Newnham 1967a).

Newnham, R. M.
1968. Simulation of pulpwood harvesting machines. Proc.: For. Eng. Conf., East Lansing, Mich. Sept. 25-27. p. 71-73.

The feller-buncher model annotated in Newnham (1967a) has been expanded to model fixed shears of the Suicard VFB, Roanoke, and Fleco types. These shears are usually mounted on the front of wheeled or tracked vehicles. They have no boom, and each tree to be felled must be approached individually. As a result, the machine "wanders" through the forest instead of traveling in a straight line.

A model for mechanized thinning is also introduced. The model uses a B-105 Feller-Processor for the thinning operation. This machine has a swing boom with attached shear that reaches out and cuts each tree. The harvesting pattern for the B-105 is a modified version of the Beloit-LRA model in which trees directly in the path of the harvester and to the side and rear are harvested. A new variable "crown resistance" has been introduced into the model.

Newnham, R. M., and S. Sjunnesson.
1969. A FORTRAN program to simulate harvesting machines for mechanized thinning. For. Manage. Res. Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-23. 48 p.

The FORTRAN program to simulate the mechanized thinning operation annotated in Newnham (1968) and its use are given.

Newnham, R. M.
1970. Productivity of harvesting machines designed for thinning: estimation by simulation. For. Manage. Res. Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-25. 29 p.

With the model annotated in Newnham (1968), the "parameters describing the B-105 Feller-Processor and its method of operation, have been tested over a range of values in order to estimate the potential productivity of the machine and to suggest areas in which its design could be improved." Felling and extraction accounted for 90 percent of the operation time, and reductions in this operation by redesign could save as much as 36.9 percent. The report represents the attainment of one of the author's objectives stated in Newnham (1967a).

Newnham, R. M.
1971. CANLOG—The new CFS harvesting machine simulator. Pulp Pap. Mag. of Can. 72(3):107–112.

CANLOG is designed to remove operational restrictions of Newham's previously designed harvesting machine simulators. The new model can account for an asymmetrical sweep of the felling boom, have cut trees swung to a point other than the rear of the machine, have the operator's cab or the processing unit restrict the swing of the boom, and have a processing method different from the one conceived for the thinning model.

The paper reports on the test of six types of harvesting machines in four test stands. The machines range from a full tree feller-buncher to a shortwood thinning feller-delimber-buncher. The stands are three natural stands of 1,436; 2,063; and 3,602 ft^3 per acre and one 8 ft x 8 ft plantation of 3,016 ft^3 per acre.

Newnham, R. M.
1972. Simulation of machines for the continuous felling of trees. For. Manage. Res. and Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-46. 22 p.

The model simulates the mowing down of small trees in dense stands by the uninterrupted forward movement of a harvesting machine. The object of the simulation is to study the forces present and the blade configuration of the harvester.

Rogers, Nelson, K.
1972. Uses of computer simulation techniques to help solve pulpwood harvesting and transportation problems. TAPPI 55(5):772–776.

A research program at Georgia Tech to study the systems components of the harvesting and transportation of pulpwood resulted in the construction of several simulation models as tools for analysis. Models addressing "long-range forecasting, organization and communications design, variation of production alternatives and sequences, management of resources under various allocation policies, testing machinery design options, and the evaluation of financial policies" are discussed. (Two models, Stark's "simulation model for the common harvesting systems of the southern pine region", and Bertils' "GPSS II model to evaluate terrain capabilities of typical pulpwood harvesting vehicles" are discussed elsewhere in the report.)

Santesson, Mona, and Sven Sjunnesson.
1972. Simulation model for thinning

machines. Inst. Skogsteknik, Res. Notes, Nr. 49.

The model described is a modification of a thinning systems simulation model (Newnham, Sjunnesson 1969). Programming has been simplified, and a thinning machine with bouquet-handling capabilities has been added. The bouquet-handling machine was modeled and outproduced the single-felling-head machines on all types of terrain.

Woodland, C.
1970. An application of systems simulation to the economic analysis of logging systems. Pulp Pap. Mag. of Can. 69(3):73–76.

This model, developed at the Spruce Falls Power and Paper Company Ltd., is a FORTRAN decision model that provides for the analysis and evaluation of new logging systems and equipment. The model is not a true simulation because it does not involve random sampling. It does, however, generate many different possible combinations and by relating each combination to some final cost criterion allows comparisons of relative profitability for different combinations.

The model essentially is an evaluation of a decision tree for many possible logging alternatives, and performs two related functions: 1) generates answers to "what if" questions by producing the effect on a cost criterion when values of key variables are changed, and 2) produces an expected total capital expenditure and expected operating cost per cord for each harvesting configuration.

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GOULET, DANIEL V., DONALD L. SIROIS, AND RONALD H. IFF.

1979. A survey of timber harvesting simulation models for use in the South. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-25, 15 p. South. For. Exp. Stn., New Orleans, La.

Reviews literature about nine forest harvesting simulation models with potential for simulating southern operations. From the nine, five appear useful enough to warrant further analysis. An annotated bibliography of associated forest harvesting simulation literature is appended.

Additional keywords: simulation, logging, computer models, forest harvesting, survey, planning.

U.S. Department of Agriculture/Forest Service
General Technical Report SO-26

A PRACTICAL FIELD METHOD OF
SITE EVALUATION FOR COMMERCIALLY IMPORTANT SOUTHERN HARDWOODS

1980

James B. Baker
W. M. Broadfoot

YCAMORE
WAMP CHESTNUT OAK
ELLOW POPLAR
HERRYBARK OAK
ECAN ■ GREEN ASH
UGARBERRY
ACKBERRY ■ SWEETGUM
UTTALL OAK
ILLOW OAK
HUMARD OAK
OTTONWOOD
ATER OAK

Southern
Forest
Experiment
Station

SUMMARY

This paper provides a method of site evaluation for cottonwood, green ash, hackberry, sugarberry, pecan, sweetgum, sycamore, yellow-poplar, and cherrybark, Nuttall, Shumard, swamp chestnut, water and willow oaks. The method incorporates an evaluation of the physical, moisture, nutrient, and aeration properties of a soil into a site quality rating. Field tests have demonstrated the accuracy of the technique. The site evaluation technique also provides a basis for possible soil improvement treatments for the 14 hardwood species and estimates of potential productivity for cottonwood, sweetgum, and sycamore plantations.

1979

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PREFACE

In 1977, we published "A Practical Field Method of Site Evaluation for Eight Important Southern Hardwoods" (Baker and Broadfoot 1977) Demand for the guide was great and many requested us to expand it to include other commercially important southern hardwoods. This publication is intended to satisfy those requests.

The site evaluation tables for the original eight species are included here but have been slightly modified to make them clearer and more useful. In addition, site evaluation tables are now provided for six more southern hardwoods (hackberry, sugarberry, yellow-poplar, pecan, and Shumard and swamp chestnut oaks). To make finding a table for a particular species easier, we have added a TABLE OF CONTENTS, and put the evaluation tables in alphabetical order for easy reference. Estimated stand and production data for sweetgum and sycamore are now included (the earlier guide had these data for cottonwood only), and the Explanation of Terms in the APPENDIX has been expanded.

A Practical Field Method of Site Evaluation or Commercially Important Southern Hardwoods

JAMES B. BAKER
AND
W. M. BROADFOOT

This field guide is for use in estimating the suitability of sites for e following southern hardwood species: cottonwood *(Populus deltoides)*, een ash *(Fraxinus pennsylvanica)*, pecan *(Carya illinoensis)*, sycamore *latanus occidentalis)*, sweetgum *(Liquidambar styraciflua)*, yellow-oplar *(Liriodendron tulipifera)*, hackberry *(Celtis occidentalis)*, sugar-erry *(C. laevigata)*, cherrybark oak *(Quercus falcata* var. *pagodaefolia)*, uttall oak *(Q. nuttallii)*, Shumard oak *(Q. shumardii)*, water oak *(Q. gra)*, willow oak *(Q. phellos)*, and swamp chestnut oak *(Q. michauxii)*.

In establishing hardwood plantations, the forest manager must know hether a site is suitable for a particular species, and for investment anning he should have some idea of the potential productivity of the e. Tables 1-12 are the guides for applying the site-evaluation method; structions on their use are given beginning on page 2. For cottonwood, eetgum, and sycamore, tables 13 and 14 give estimated ranges in ee growth and volume production. A glossary of terms that may be familiar to many readers is included as an appendix.

BACKGROUND

Many acres of hardwood plantations are established each year roughout the eastern United States. Johnson and Kerr (1976) reported at by 1981 cottonwood plantations alone could total about 70,000 acres, 30,000-acre increase in 5 years. Other species, such as sycamore, eetgum, and green ash, are also being planted at accelerated rates roughout the South.

Until recently the techniques available to aid in site selection and aluation for hardwoods involved either objective or subjective

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approaches which had inherent shortcomings that limit their usefulness The problems of objectively selecting and quantifying measurable soi variables that consistently reflect the growth potential of hardwood over wide geographic areas appear to be insurmountable (Broadfoot 1969) On the other hand, subjective approaches provide only broad classes o soil suitability or productivity for hardwoods (Broadfoot 1964, Broadfoo et al. 1972), Maisenhelder 1960, McKnight 1970, and Smith 1957).

Our technique of site evaluation combines the best features o objective and subjective approaches. The technique is based on ou experience and is not the result of formal experimentation, but it provides foresters with an accurate way of evaluating a site's suitabilit for any of 14 hardwood species. The method can also be used to obtai estimates of potential volume production of sweetgum, sycamore an cottonwood at various ages.

The advantages of the technique are: (1) it provides accurat estimates of site index under any soil or site condition; (2) it can b applied throughout the southern hardwood region except in those mountainous areas where aspect is important; (3) it does not require ident fication of soil series; and (4) it provides guidelines for soil ameliorativ treatments. In the future, the method could possibly be modified t include species of trees from throughout the world if allowance is mad for differences in climate, soils, and topography.

With field-plot data for hardwoods (Broadfoot 1976), the techniqu was tested for each species for a variety of soils and physiographi areas. Site index values estimated for a particular site by the ne method were compared to measured site index values obtained b Broadfoot. These comparisons were subjected to correlation analysis an to the chi-square test of accuracy (Freese 1960). On the average, 20 site were tested for each species; correlation coefficients ranged from 0.9 for sweetgum to 0.99 for cottonwood. The chi-square test for accurac indicated that the new evaluation technique should provide estimat of site index that are within 5 feet of measured site index values 9 percent of the time, if all soil-site factors are correctly evaluated.

BASIS FOR AND DEVELOPMENT OF THE TECHNIQUE

Growth of hardwoods is dependent primarily on four major so factors (Broadfoot 1969, Broadfoot et al. 1972, Kaszkurewicz 197 Schreiner 1959, Waring 1961). These factors are:

(1) Soil physical condition.
(2) Moisture availability during the growing season.
(3) Nutrient availability.
(4) Aeration.

Each major factor consists of many soil and site properties that affe tree growth. The interaction of these properties within and among th major soil factors makes evaluation of a site a complex task.

The basis of our approach is the assumption that each of the maj soil factors is responsible for a certain percentage of tree growth. The proportion of growth accounted for by each major factor is composed of the contributions made by each of its soil-site properties.

We will use cottonwood to illustrate how the approach and the site evaluation guides were developed. We assumed maximum height growth of 130 feet in 30 years for cottonwood on an ideal site and assigned a site quality rating (SQR) to each of three possible conditions (best, medium, and poor) of each soil-site property for the four major soil factors (see numbers in brackets, table 1). We derived these ratings by determining what percentage of the 130 feet was contributed by each of the four major soil factors (fig. 1). For example, physical condition is responsible for about 35 percent (46 of 130 feet) of cottonwood growth, moisture availability also explains about 35 percent, nutrient availability accounts for about 20 percent (26 of 130 feet) and aeration explains about 10 percent (12 of 130 feet). Next, we assessed the influence of soil-site properties on each of the four major soil factors. For example, of the five soil-site properties that influence soil physical conditions, soil depth is responsible for about 35 percent (16 of 46 feet) of the total effect of these properties on soil physical condition (fig. 1). Texture, compaction, structure, and past use contribute 25 percent (11 of 46 feet), 20 percent (9 of 46 feet), 10 percent (5 of 46 feet), and 10 percent. Similar appraisals were made of soil-site properties for each of the other three major soil factors. Therefore, on an ideal site the sum of the SQR's for each major soil factor corresponds to a site index of 130 feet at 30 years. After SQR values were established for the best site condition, they were assigned to medium and poor sites by estimating height reductions caused by less than optimal conditions. The site evaluation guides for the other species (tables 2-12) were developed in like manner.

Tables 1-12 list the major soil factors and soil-site properties for the 14 species. The tables also present a range of soil-site conditions, from best to poor, that are likely to occur for each soil property. The soil-site conditions for each property are assigned numerical site-quality ratings (SQR), which are given in brackets.

FIELD USE OF THE EVALUATION TECHNIQUE

To obtain an SQR value for a particular species, match the soil-site conditions of your area as closely as possible to the range of conditions listed for each soil-site property in the appropriate table. A 30-year site index for cottonwood and a 50-year site index for the other species is obtained by adding the SQR's for each soil-site property. If a total SQR for any site does not exceed 80 feet for cottonwood; 75 feet for sweetgum and Nuttall oak; 70 feet for sycamore, pecan, yellow-poplar, and water, willow, cherrybark, and Shumard oaks; 65 feet for green ash and swamp chestnut oak; and 55 feet for hackberry and sugarberry, the area should be considered unsuitable for that species unless amelioration is used to improve soil conditions.

If an exact match is not possible, interpolate between conditions listed in the tables. If you are unable to determine a specific soil-site condition, do not hesitate to make an educated guess; a few poor estimations probably will not cause serious errors in the final site quality rating. A few hours of instruction from a soil scientist should enable people who are unfamiliar with various soil-site conditions to make accurate estimates.

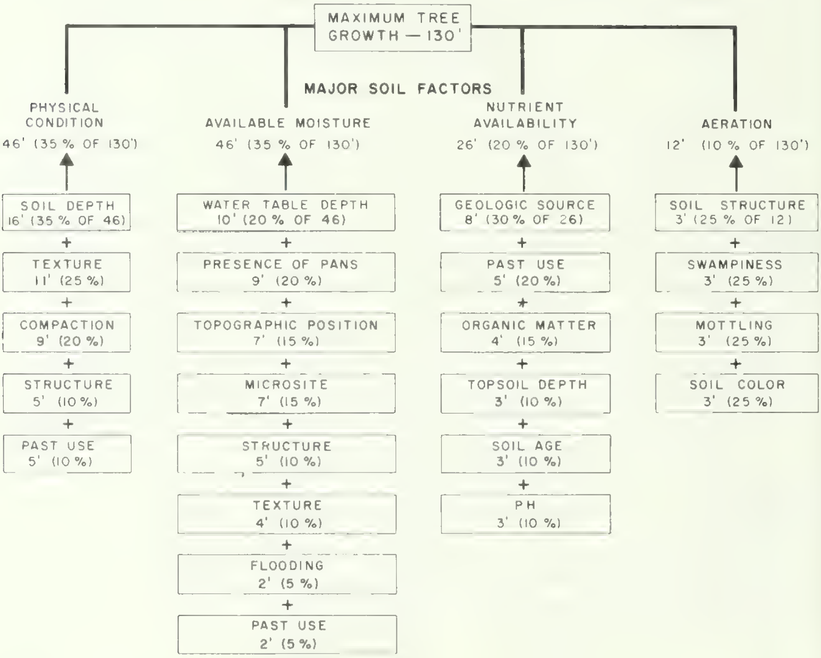

Figure 1.—*Contribution of various soil-site properties to the four major soil factors and to cottonwood growth (maximum growth expected on an ideal site at age 30).*

As an example of how the technique is applied, let us assume that the location to be evaluated is a recently abandoned old field in the Mississippi River floodplain that had been under intensive agronomic cropping for 25 years. The area is level and not subject to flooding. The soil is a loam with no profile development; it is granular in structure but is moderately compacted and has a plowpan at 10 inches. It is brown and mottled at 36 inches. A water table occurs at 5 feet during the growing season, pH is 6.5, and there is less than 1 percent organic matter in the A-horizon.

The SQR's for each soil-site characteristic of the hypothetical area, taken from table 1, are summed up and produce the following site evaluation for cottonwood:

MAJOR SOIL FACTORS

Physical condition		(2) Moisture availability		(3) Nutrient availability		(4) Aeration	
		Water table ..	10	Geologic source	8		
		Pans .	6				
Soil depth and pans . .	11	Position	7	Past use	-3		
Texture	11	Microsite	5	% organic matter	-3	Structure	3
Compaction .	6	Structure	5	Topsoil .	3	Swampiness	3
Structure	5	Texture	4	Soil age	3	Mottling	3
Past use	-2	Flooding	-1	pH	3	Color	3
		Past use	-1				
Total	31 ft		35 ft		11 ft		12 ft
(Total possible)	(46 ft)		(46 ft)		(26 ft)		(12 ft)

TOTAL SQR OR SITE INDEX = 89 ft

This evaluation indicates that the site index for cottonwood on this particular area is 89 feet at 30 years.

By comparing the value obtained for each major factor with the maximum values possible for an ideal site, we can determine which major factor limits growth. In the example, physical condition received 31 of the 46 (67 percent) points possible; moisture availability and aeration received 76 and 100 percent, respectively, of the total possible points. Nutrient availability, however, received only 42 percent of its total possible points. Thus, a lack of sufficient nutrients would probably limit growth on this site, and fertilization might be used to improve the growth of cottonwood.

ESTIMATES OF POTENTIAL PRODUCTIVITY FOR COTTONWOOD, SWEETGUM, AND SYCAMORE BY SITE CLASSES

Once a forest manager has calculated the SQR for cottonwood, sweetgum, or sycamore for an area, he can obtain from tables 13 or 1 an estimate of productivity for various stages of development. These production estimates were measured from yields in cottonwood plantations through age 15 and from natural stand data for ages 20 through 3 years. Sweetgum and sycamore yields were estimated as a proportion of cottonwood yields. At present, plantation data are not adequate to prepare productivity tables for the other species. Derivation of the estimates for cottonwood was based on the following assumptions:

(1) Site preparation and plantation culture through the first growing season as described by McKnight (1970).

(2) Planting density of approximately 430 trees per acre; 20 percent planting mortality and 1 percent natural mortality per year after establishment.

(3) Proper thinning to maintain adequate growing space for crop trees. These thinnings included:

a. One-half of the trees (½ of the basal area) removed per acre as row thinnings on the Class I and II sites at age 5.

b. One-half of the trees (½ of the BA) removed as row thinnings on the Class III sites and one-third of the BA (38 percent of the trees from the lower half of the diameter range) removed by selection on the Class I and II sites at age 10.

c. One-third of the BA (38 percent of the trees from the lower half of the diameter range) removed by selection on all site classes at age 15.

d. One-third of the BA (38 percent of the trees from the lower half of the diameter range) removed by selection on the Class I sites at age 20.

Production estimates presented at each age are for standing trees at that time and do not include previous thinnings, but net production (final harvest cut + previous thinnings) is given for age 30. Net production for ages other than 30 years can be calculated by summing the volume of standing trees at the intermediate age and the volume obtained from previous thinnings. For example, net production in cords for cottonwood for the Class I sites at age 15 is 50 + (1/3 of 46) or 15.3 + (1/2 of 17) or 8.5, giving a total of 73.8 cords per acre (table 8).

It should be noted that values for ft.^{3}, cords, M bm, and dry matter represent the total production for a single product. For example, for cottonwood at age 30 the Class I sites would produce 11,170 ft.^{3} or 124 cords or 39 and 49 M bm (Doyle and Int.) or 830 tons of stem per acre (table 8). Estimates are not provided for multiple products.

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able 1. — *Site Evaluation Guide for COTTONWOOD*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [16][2]	Medium depth (2-4 feet), or a soil with a plowpan [11]	Shallow soil (< 2 feet), or a soil with an inherent pan [-11]
Texture (in rooting zone)	Medium-textured; silty or loamy [11]	Coarse-textured; sandy [8]	Fine-textured; clayey [-4]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc [9]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [6]	Strongly compacted; tight, bulk density > 1.7 g/cc [-3]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [5]	Prismatic; blocky [3]	Massive (if clayey); platy [-3]
Past use and present cover	Undisturbed; near-virgin forest cover [5]	Moderate cultivation; cultivated < 20 years, or open with grass cover [2]	Intensive cultivation; cultivated > 20 years, or open and bare [-2]

Continued

Table 1. — *Site Evaluation Guide for COTTONWOOD (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
Factor 2. Moisture availability during growing season			
Water table depth	2-6′ [10]	1-2′; 7-10′ [7]	<1′ [unsuitable]; >10′ [0][3]
Artificial or inherent pans	No pans [9]	Plowpan [6]	Inherent pan [-6]
Topographic position	Floodplain or stream bottom [7]	Stream terraces or lower slopes [5]	Upland [-5]
Microsite	Concave; depression, pocket, trough [7]	Level; flat [5]	Convex; ridge, mound [-2]
Structure (in rooting zone)	Granular; structureless, massive (if silty, loamy, or clayey); stratified [5]	Prismatic; blocky [3]	Structureless, single-grained (if sandy); platy [-3]
Texture (in rooting zone)	Silty or loamy (or stratified) [4]	Clayey [2]	Sandy [-2]
Flooding	Winter through spring [2]	Winter only [1]	None [-1]; continuous [unsuitable]
Past use and present cover	Undisturbed; near-virgin forest cover [2]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [-1]

Continued

Table 1. — *Site Evaluation Guide for COTTONWOOD (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [8]	Mixed Coastal Plain and other [5]	Coastal Plain [-5]
Past use and present cover	Undisturbed; near-virgin, forest cover, cultivated < 5 years [5]	Moderate cultivation; cultivated 5-10 years, or open with grass [3][4]	Intensive cultivation; cultivated > 10 years, or open and bare [-3][4]
Organic matter (A-horizon)	> 2% [4]	1-2% [3]	< 1% [-3]
Depth of topsoil (A-horizon)	> 6″ or no profile development [3]	3-6″ [2]	< 3″ [-2]
Soil age	Young, no profile development (Entisols) [3]	Medium, moderate profile development (Inceptisols) [2]	Old, well-developed profile, leached (Alfisols, Ultisols) [-2]
pH (in rooting zone	5.5-7.5 [3]	4.5-5.5 or 7.6-8.5 [2]	< 4.5 or > 8.5 [-2]
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty [3]	Prismatic; blocky [2]	Massive (if clayey); platy [-2]
Swampiness	Wet in winter only [3]	Wet January-July [2]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [3]	None to 8″ depth [2]	Mottled to surface or gray mineral soil [-2]
Soil color (in rooting zone)	Black, brown, red [3]	Yellow, brownish-gray [2]	Gray [-2]

130 feet at 30 years maximum S.I.; 80 feet minimum acceptable S.I.

Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

If the soil is a sand or loamy sand, then [-20].

If cultural practices included annual fertilization, then [4].

Table 2. — *Site Evaluation Guide for GREEN ASH*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [8][2]	Medium depth (2-4 feet), or a soil with a plowpan [5]	Shallow soil (< 2 feet), or a soil with an inherent pan [-3]
Texture (in rooting zone)	Medium-textured; silty or loamy [2]	Coarse-textured; sandy [1]	Fine-textured; clayey [-1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc [5]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [3]	Strongly compacted; tight, bulk density > 1.7 g/cc [0]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [2]	Prismatic; blocky [1]	Massive (if clayey); platy [0]
Past use and present cover	Undisturbed; near-virgin forest cover [4]	Moderate cultivation; cultivated < 20 years, or open with grass cover [2]	Intensive cultivation; cultivated > 20 years, or open and bare [1]

Continued

Table 2. — *Site Evaluation Guide for GREEN ASH (con t)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
Factor 2. Moisture availability during growing season			
Water table depth	2-6′ [10]	1-2′ [7]; 7-10′ [5]	<1′ [0]; >10′ [-5][3]
Artificial or inherent pans	No pans [9]	Plowpan [5]	Inherent pan [-2]
Topographic position	Floodplain or stream bottom [10]	Stream terraces or lower slopes [7]	Upland [0]
Microsite	Concave; depression, pocket, trough [5]	Level; flat [3]	Convex; ridge, mound [0]
Structure (in rooting zone)	Granular; structureless, massive (if silty, loamy, or clayey); stratified [2]	Prismatic; blocky [1]	Structureless, single-grained if sandy; platy [-1]
Texture (in rooting zone)	Silty or loamy, (or stratified) [2]	Clayey [1]	Sandy [-1]
Flooding	Winter through spring [7]	Winter only [4]	None [-3]; continuous [unsuitable]
Past use and present cover	Undisturbed; near-virgin forest cover [2]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [0]

Continued

Table 2. — *Site Evaluation Guide for GREEN ASH (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [6]	Mixed Coastal Plain and other [2]	Coastal Plain [-2]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated < 5 years [6]	Moderate cultivation; cultivated 5-10 years, or open with grass [3][4]	Intensive cultivation; cultivated > 10 years, or open and bare [-1][4]
Organic matter (A-horizon)	> 2% [4]	1-2% [2]	< 1% [-1]
Depth of topsoil (A-horizon)	> 6″ or no profile development [4]	3-6″ [2]	< 3″ [-1]
Soil age	Young, no profile development (Entisols) [3]	Medium, moderate profile development (Inceptisols) [2]	Old, well-developed profile, leached (Alfisols, Ultisols) [0]
pH (in rooting zone)	5.5-7.5 [3]	4.5-5.5 or 7.6-8.5 [2]	< 4.5 or > 8.5 [-2]
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty [3]	Prismatic; blocky [2]	Massive (if clayey); platy [0]
Swampiness	Wet in winter only [3]	Wet January-July [2]	Waterlogged all year [0]
Mottling	None to 18″ depth [2]	None to 8″ depth [1]	Mottled to surface or gray mineral soil [0]
Soil color (in rooting zone)	Black, brown, red [2]	Yellow, brownish-gray [1]	Gray [0]

[1] 105 feet at 50 years maximum S.I.; 65 feet minimum acceptable S.I.

[2] Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

[3] If the soil is a sand or loamy sand, then [-10].

[4] If cultural practices included annual fertilization, then [4].

Table 3. — *Site Evaluation Guide for HACKBERRY and SUGARBERRY*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [6][2]	Medium depth (2-4 feet), or a soil with a plowpan [4]	Shallow soil (< 2 feet), or a soil with an inherent pan [-2]
Texture (in rooting zone)	Medium-textured; silty or loamy [5]	Coarse-textured; sandy [3]	Fine-textured; clayey [1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc [5]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [3]	Strongly compacted; tight, bulk density > 1.7 g/cc [-1]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [4]	Prismatic; blocky [3]	Massive (if clayey); platy [1]
Past use and present cover	Undisturbed; near-virgin, forest cover [5]	Moderate cultivation; cultivated < 20 years, or open with grass cover [2]	Intensive cultivation; cultivated > 20 years, or open and bare [0]

Continued

Table 3. — *Site Evaluation Guide for HACKBERRY and SUGARBERRY (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
Factor 2. Moisture availability during growing season			
Water table depth	2-6′ [5]	1-2′; 7-10′ [3]	< 1′ [unsuitable]; > 10′ [0][3]
Artificial or inherent pans	No pans [5]	Plowpan [2]	Inherent pan [-2]
Topographic position	Floodplain or stream bottom [4]	Stream terraces or lower slopes [2]	Upland [-4]
Microsite	Concave; depression, pocket, trough [2]	Level; flat [1]	Convex; ridge, mound [-2]
Structure (in rooting zone)	Granular; blocky; structureless; massive (if silty, loamy, or clayey); stratified [3]	Prismatic; platy [2]	Structureless; single-grained if sandy [1]
Texture (in rooting zone)	Silty or loamy, (or stratified) [2]	Clayey [1]	Sandy [0]
Flooding	Winter through spring [2]	Winter only [1]	None [0] Continuous [Unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [2]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [0]

Continued

Table 3. — *Site Evaluation Guide for HACKBERRY and SUGARBERRY (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [6]	Mixed Coastal Plain and other [4]	Coastal Plain [0]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated < 5 years [4]	Moderate cultivation; cultivated 5-10 years, or open with grass [2][4]	Intensive cultivation; cultivated > 10 years, or open and bare [0][4]
Organic matter (A-horizon)	> 2% [4]	1-2% [2]	< 1% [-2]
Depth of topsoil (A-horizon)	>6" or no profile development [4]	3-6" [2]	< 3" [0]
Soil age	Young, no profile development (Entisols) [4]	Medium, moderate profile development (Inceptisols) [2]	Old, well-developed profile, leached (Alfisols; Ultisols) [1]
pH (in rooting zone)	4.0-8.5 [3]	4.0-8.5 [3]	4.0 -8.5 [3]

Continued

Table 3. — *Site Evaluation Guide for HACKBERRY and SUGARBERRY (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty [7]	Prismatic; blocky [5]	Massive (if clayey); platy [0]
Swampiness	Wet in winter only [6]	Wet January-July [4]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [7]	None to 8″ depth [5]	Mottled to surface or gray mineral soil [2]
Soil color (in rooting zone)	Black, brown, red [5]	Yellow, brownish-gray [4]	Gray [3]

[1] 100 feet at 50 years maximum S.I.; 55 feet minimum acceptable S.I.

[2] Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

[3] If the soil is sand or loamy sand, then [-5].

[4] If cultural practices included annual fertilization, then [3].

Table 4. — *Site Evaluation Guide for CHERRYBARK OAK*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [6][2]	Medium depth (2-4 feet), or a soil with a plowpan [4]	Shallow soil (< 2 feet), or a soil with an inherent pan [-2]
Texture (in rooting zone)	Medium-textured; silty or loamy [5]	Coarse-textured; sandy [3]	Fine-textured; clayey [1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc [6]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [4]	Strongly compacted; tight, bulk density > 1.7 g/cc [-2]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty. [6]	Prismatic; blocky [4]	Massive (if clayey); platy [0]
Past use and present cover	Undisturbed; near-virgin forest cover [8]	Moderate cultivation; cultivated < 20 years, or open with grass cover [4]	Intensive cultivation; cultivated > 20 years, or open and bare [1]

Continued

Table 4. — *Site Evaluation Guide for CHERRYBARK OAK (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
Factor 2. Moisture availability during growing season			
Water table depth	2-6′ [6]	1-2′; 7-10′ [3]	<1′ [unsuitable]; >10′ [-3][3]
Artificial or inherent pans	No pans [6]	Plowpan [3]	Inherent pan [-2]
Topographic position	Floodplain or stream bottom [6]	Stream terraces or lower slopes [4]	Upland [0]
Microsite	Concave; depression, pocket, trough [2]	Level; flat [1]	Convex; ridge, mound [0]
Structure (in rooting zone)	Granular; structureless, massive (if silty, loamy, or clayey); stratified [5]	Prismatic; blocky [3]	Structureless, single-grained if sandy; platy [-1]
Texture (in rooting zone)	Silty or loamy, (or stratified) [5]	Clayey [3]	Sandy [0]
Flooding	Winter through spring [6]	Winter only [3]	None [0]; continuous [unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [2]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [0]

Continued

Table 4. — *Site Evaluation Guide for CHERRYBARK OAK (con't)*

Soil-site property	Soil-site condition and relative quality[2]		
	Best	Medium	Poor
Factor 3. Nutrient availability			
Geologic source	Mississippi River, Loess, Blackland [3]	Mixed Coastal Plain and other [1]	Coastal Plain [0]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated < 5 years [5]	Moderate cultivation; cultivated 5-10 years, or open with grass [3][4]	Intensive cultivation; cultivated > 10 years, or open and bare [1][3]
Organic matter (A-horizon)	> 2% [5]	1-2% [3]	< 1% [0]
Depth of topsoil (A-horizon)	> 6″ or no profile development [5]	3-6″ [2]	< 3″ [-3]
Soil age	Young, no profile development (Entisols) [2]	Medium, moderate profile development (Inceptisols) [1]	Old, well-developed profile, leached (Alfisols, Ultisols) [0]
pH (in rooting zone)	4.5-5.5 [5]	5.6-7.5 or 4.0-4.4 [3]	< 4.0 [-2] > 7.5 [Unsuitable]
Factor 4. Aeration			
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty [8]	Prismatic; blocky [4]	Massive (if clayey); platy [0]
Swampiness	Wet in winter only [8]	Wet January-July [4]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [8]	None to 8″ depth [4]	Mottled to surface or gray mineral soil [-2]
Soil color (in rooting zone)	Black, brown, red [7]	Yellow, brownish-gray [4]	Gray [-2]

[1] 125 feet at 50 years maximum S.I.; 70 feet minimum acceptable S.I.

[2] Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

[3] If the soil is a sand or loamy sand, then [-10].

[4] If cultural practices included annual fertilization, then [4].

Table 5. — *Site Evaluation Guide for NUTTALL OAK*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [8][2]	Medium depth (2-4 feet), or a soil with a plowpan [5]	Shallow soil (< 2 feet), or a soil with an inherent pan [-3]
Texture (in rooting zone)	Medium-textured; silty or loamy [2]	Coarse-textured; sandy [1]	Fine-textured; clayey [-1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc [6]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [3]	Strongly compacted; tight, bulk density > 1.7 g/cc [0]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [3]	Prismatic; blocky [2]	Massive (if clayey); platy [0]
Past use and present cover	Undisturbed; near-virgin forest cover [5]	Moderate cultivation; cultivated < 20 years, or open with grass cover [3]	Intensive cultivation; cultivated > 20 years, or open and bare [1]

Continued

Table 5. — *Site Evaluation Guide for NUTTALL OAK (con't)*

Soil-site property	Soil-site condition and relative quality[1]		
	Best	Medium	Poor
	Factor 2. Moisture availability during growing season		
Water table depth	2-6′ [9]	1-2′; 7-10′ [6]	1′ [unsuitable]; 10′ [0][3]
Artificial or inherent pans	No pans [9]	Plowpan [4]	Inherent pan [-2]
Topographic position	Floodplain or stream bottom [8]	Stream terraces or lower slopes [5]	Upland [0]
Microsite	Concave; depression, pocket, trough [4]	Level; flat [2]	Convex; ridge, mound [0]
Structure (in rooting zone)	Granular; structureless, massive (if silty, loamy, or clayey); stratified [2]	Prismatic; blocky [1]	Structureless, single-grained if sandy; platy [0]
Texture (in rooting zone)	Silty or loamy, (or stratified) [2]	Clayey [1]	Sandy [0]
Flooding	Winter through spring [6]	Winter only [3]	None [0] continuous [unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [2]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [0]

Continued

Table 5. — *Site Evaluation Guide for NUTTALL OAK (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [3]	Mixed Coastal Plain and other [1]	Coastal Plain [-1]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated < 5 years [6]	Moderate cultivation; cultivated 5-10 years, or open with grass [3][4]	Intensive cultivation; cultivated > 10 years, or open and bare [0][4]
Organic matter (A-horizon)	> 2% [6]	1-2% [3]	< 1% [0]
Depth of topsoil (A-horizon)	> 6″ or no profile development [6]	3-6″ [3]	< 3″ [-3]
Soil age	Young, no profile development (Entisols) [3]	Medium, moderate profile development (Inceptisols) [1]	Old, well-developed profile, leached (Alfisols; Ultisols) [-1]
pH (in rooting zone)	4.5-5.5 [6]	5.6-7.5 or 4.0-4.4 [4]	4.0 [-2] > 7.5 [Unsuitable]
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty [7]	Prismatic; blocky [5]	Massive (if clayey); platy [0]
Swampiness	Wet in winter only [7]	Wet January-July [5]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [5]	None to 8″ depth [3]	Mottled to surface or gray mineral soil [1]
Soil color (in rooting zone)	Black, brown, red [5]	Yellow, brownish-gray [2]	Gray [0]

[1] 120 feet at 50 years maximum S.I.; 75 feet minimum acceptable S.I.

[2] Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

[3] If the soil is a sand or loamy sand, then [-10].

[4] If cultural practices included annual fertilization, then [4].

Table 6. — *Site Evaluation Guide for SHUMARD OAK*[1]

Soil-site property	Soil-site condition and relative quality Best	 Medium	 Poor
Factor 1. Physical condition			
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [6][2]	Medium depth (2-4 feet), or a soil with a plowpan [4]	Shallow soil (< 2 feet), or a soil with an inherent pan [-2]
Texture (in rooting zone)	Medium-textured; silty or loamy [5]	Coarse-textured; sandy [3]	Fine-textured; clayey [1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc [6]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [4]	Strongly compacted, tight, bulk density > 1.7 g/cc [-2]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [6]	Prismatic; blocky [4]	Massive (if clayey); platy [0]
Past use and present cover	Undisturbed; near-virgin, forest cover [8]	Moderate cultivation; cultivated < 20 years, or open with grass cover [4]	Intensive cultivation; cultivated > 20 years, or open and bare [1]

Continued

Table 6. — *Site Evaluation Guide for SHUMARD OAK (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
Factor 2. Moisture availability during growing season			
Water table depth	2-6′ [5]	1-2′; 7-10′ [2]	< 1′ [unsuitable]; > 10′ [0]³
Artificial or inherent pans	No pans [5]	Plowpan [2]	Inherent pan [-1]
Topographic position	Floodplain or stream bottom [5]	Stream terraces or lower slopes [3]	Upland [0]
Microsite	Concave; depression, pocket, trough [2]	Level; flat [1]	Convex; ridge, mound [0]
Structure (in rooting zone)	Granular; blocky; structureless; massive (if silty, loamy, or clayey); stratified [4]	Prismatic; platy [2]	Structureless; single-grained if sandy [0]
Texture (in rooting zone)	Silty or loamy, (or stratified) [4]	Clayey [2]	Sandy [0]
Flooding	Winter through spring [5]	Winter only [2]	None [1] Continuous [Unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [2]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [0]

Continued

Table 6. — *Site Evaluation Guide for SHUMARD OAK (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [4]	Mixed Coastal Plain and other [2]	Coastal Plain [1]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated 5 years [6]	Moderate cultivation; cultivated 5-10 years, or open with grass [4][1]	Intensive cultivation; cultivated 10 years, or open and bare [2][1]
Organic matter (A-horizon)	2% [5]	1-2% [3]	1% [0]
Depth of topsoil (A-horizon)	6″ or no profile development [6]	3-6″ [3]	3″ [-4]
Soil age	Young, no profile development (Entisols) [3]	Medium, moderate profile development (Inceptisols) [2]	Old, well-developed profile, leached (Alfisols; Ultisols) [1]
pH (in rooting zone)	4.5-5.5 [5]	5.6-7.5 or 4.0-4.4 [3]	4.0 [-2] 7.5 [Unsuitable]

Continued

Table 6. — *Site Evaluation Guide for SHUMARD OAK (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty [7]	Prismatic; blocky [3]	Massive (if clayey); platy [1]
Swampiness	Wet in winter only [7]	Wet January-July [3]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [8]	None to 8″ depth [4]	Mottled to surface or gray mineral soil [-1]
Soil color (in rooting zone)	Black, brown, red [8]	Yellow, brownish-gray [4]	Gray [-1]

[1] 120 feet at 50 years maximum S.I.; 70 feet minimum acceptable S.I.

[2] Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

[3] If the soil is sand or loamy sand, then [-5].

[4] If cultural practices included annual fertilization, then [5].

Table 7. — *Site Evaluation Guide for SWAMP CHESTNUT OAK*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [8][2]	Medium depth (2-4 feet), or a soil with a plowpan [5]	Shallow soil (< 2 feet), or a soil with an inherent pan [-1]
Texture (in rooting zone)	Medium-textured; silty or loamy [4]	Coarse-textured; sandy [2]	Fine-textured, clayey [1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc [5]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [3]	Strongly compacted, tight, bulk density > 1.7 g/cc [-1]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [5]	Prismatic; blocky [3]	Massive (if clayey); platy [0]
Past use and present cover	Undisturbed; near-virgin, forest cover [6]	Moderate cultivation; cultivated < 20 years, or open with grass cover [3]	Intensive cultivation; cultivated > 20 years, or open and bare [0]

Continued

Table 7. — *Site Evaluation Guide for SWAMP CHESTNUT OAK (con't)*

Soil-site property	Soil-site condition and relative quality Best	 Medium	 Poor
Factor 2. Moisture availability during growing season			
Water table depth	2-6′ [4]	1-2′; 7-10′ [3]	< 1′ [unsuitable]; > 10′ [-1][3]
Artificial or inherent pans	No pans [6]	Plowpan [3]	Inherent pan [-2]
Topographic position	Floodplain or stream bottom [6]	Stream terraces or lower slopes [4]	Upland [-1]
Microsite	Concave; depression, pocket, trough [2]	Level; flat [1]	Convex; ridge, mound [0]
Structure (in rooting zone)	Granular; blocky; structureless; massive (if silty, loamy, or clayey); stratified [4]	Prismatic; platy [2]	Structureless; single-grained if sandy [0]
Texture (in rooting zone)	Silty or loamy, (or stratified) [3]	Clayey [1]	Sandy [-1]
Flooding	Winter through spring [3]	Winter only [2]	None [0] Continuous [Unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [3]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [-1]

Continued

Table 7. — *Site Evaluation Guide for SWAMP CHESTNUT OAK (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [3]	Mixed Coastal Plain and other [1]	Coastal Plain [0]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated < 5 years [5]	Moderate cultivation; cultivated 5-10 years, or open with grass [3][4]	Intensive cultivation; cultivated > 10 years, or open and bare [1][4]
Organic matter (A-horizon)	> 2% [4]	1-2% [2]	< 1% [0]
Depth of topsoil (A-horizon)	>6″ or no profile development [5]	3-6″ [2]	<3″ [-3]
Soil age	Young, no profile development (Entisols) [2]	Medium, moderate profile development (Inceptisols) [1]	Old, well-developed profile, leached (Alfisols; Ultisols) [0]
pH (in rooting zone)	4.5-5.5 [5]	5.5-7.5 or 4.0-4.4 [3]	< 4.0 [-2] > 7.5 [Unsuitable]

Continued

Table 7. — *Site Evaluation Guide for SWAMP CHESTNUT OAK (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty [6]	Prismatic; blocky [4]	Massive (if clayey); platy [2]
Swampiness	Wet in winter only [6]	Wet January-July [4]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [7]	None to 8″ depth [4]	Mottled to surface or gray mineral soil [0]
Soil color (in rooting zone)	Black, brown, red [7]	Yellow, brownish-gray [3]	Gray [-1]

[1] 110 feet at 50 years maximum S.I.; 65 feet minimum acceptable S.I.

[2] Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

[3] If the soil is sand or loamy sand, then [-5].

[4] If cultural practices included annual fertilization, then [5].

Table 8. — *Site Evaluation Guide for WATER OAK and WILLOW OAK*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [6][2]	Medium depth (2-4 feet), or a soil with a plowpan [4]	Shallow soil (< 2 feet), or a soil with an inherent pan [-2]
Texture (in rooting zone)	Medium-textured; silty or loamy [4]	Coarse-textured; sandy [2]	Fine-textured; clayey [1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc [6]	Moderately compacted; firm, moderately tight bulk density 1.4-1.7 g/cc [4]	Strongly compacted, tight, bulk density > 1.7 g/cc [-2]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [6]	Prismatic; blocky [4]	Massive (if clayey); platy [0]
Past use and present cover	Undisturbed; near-virgin, forest cover [7]	Moderate cultivation; cultivated < 20 years, or open with grass cover [4]	Intensive cultivation; cultivated > 20 years, or open and bare [1]

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Table 8. — *Site Evaluation Guide for WATER OAK and WILLOW OAK (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
Factor 2. Moisture availability during growing season			
Water table depth	2-6′ [5]	1-2′; 7-10′ [2]	< 1′ (unsuitable); > 10′ [-3][3]
Artificial or inherent pans	No pans [5]	Plowpan [2]	Inherent pan [-2]
Topographic position	Floodplain or stream bottom [5]	Stream terraces or lower slopes [3]	Upland [0]
Microsite	Concave; depression, pocket, trough [2]	Level; flat [1]	Convex; ridge, mound [-3]
Structure (in rooting zone)	Granular; structureless, massive (if silty, loamy, or clayey); stratified [5]	Prismatic; platy [5]	Structureless; single-grained if sandy; platy [3]
Texture (in rooting zone)	Silty or loamy, (or stratified) [5]	Clayey [3]	Sandy [0]
Flooding	Winter through spring [5]	Winter only [3]	None [-1]; Continuous [unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [2]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [0]

Continued

Table 8. — *Site Evaluation Guide for WATER OAK and WILLOW OAK (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [2]	Mixed Coastal Plain and other [1]	Coastal Plain [0]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated <5 years [5]	Moderate cultivation, cultivated 5-10 years, or open with grass [3][1]	Intensive cultivation, cultivated >10 years, or open and bare [1][3]
Organic matter (A-horizon)	>2% [4]	1-2% [2]	<1% [0]
Depth of topsoil (A-horizon)	>6" or no profile development [5]	3-6" [2]	<3" [-3]
Soil age	Young, no profile development (Entisols) [2]	Medium, moderate profile development (Inceptisols) [1]	Old, well-developed profile, leached (Alfisols; Ultisols) [0]
pH (in rooting zone)	4.5-5.5 [5]	5.6-7.5 or 4.0-4.4 [3]	<4.0 [-2] >7.5 [Unsuitable]
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty [7]	Prismatic; blocky [5]	Massive (if clayey); platy [0]
Swampiness	Wet in winter only [8]	Wet January-July [4]	Waterlogged all year [Unsuitable]
Mottling	None to 18" depth [7]	None to 8" depth [5]	Mottled to surface or gray mineral soil [2]
Soil color (in rooting zone)	Black, brown, red [7]	Yellow, brownish-gray [5]	Gray [-2]

[1]15 feet at 50 years maximum S.I.; 70 feet minimum acceptable S.I.

[2] ach bracketed number indicates the site quality rating (SQR) of a particular soil-site ondition.

[3] the soil is sand or loamy sand, then [-10].

[4] cultural practices included annual fertilization, then [4].

Table 9. — *Site Evaluation Guide for PECAN*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil ($>$ 4 feet); without pan [6][2]	Medium depth (2-4 feet), or a soil with a plowpan [4]	Shallow soil ($<$ 2 feet), or a soil with an inherent pan [-2]
Texture (in rooting zone)	Medium-textured; silty or loamy [5]	Coarse-textured; sandy [4]	Fine-textured; clayey [1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density $<$ 1.4 g/cc [6]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [4]	Strongly compacted; tight, bulk density $>$ 1.7 g/cc [-2]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [4]	Prismatic; blocky [3]	Massive (if clayey); platy [1]
Past use and present cover	Undisturbed; near-virgin, forest cover [6]	Moderate cultivation; cultivated $<$ 20 years, or open with grass cover [3]	Intensive cultivation; cultivated $>$ 20 years, or open and bare [0]

Continued

Table 9. — *Site Evaluation Guide for PECAN (con't)*

Soil-site property	Soil-site condition and relative quality: Best	Medium	Poor
Factor 2. Moisture availability during growing season			
Water table depth	2-6′ [4]	1-2′; 7-10 [2]	< 1′ [unsuitable]; > 10′ [0][3]
Artificial or inherent pans	No pans [5]	Plowpan [2]	Inherent pan [-2]
Topographic position	Floodplain or stream bottom [5]	Stream terraces or lower slopes [3]	Upland [0]
Microsite	Concave; depression, pocket, trough [2]	Level; flat [1]	Convex; ridge, mound [0]
Structure (in rooting zone)	Granular; blocky; structureless; massive (if silty, loamy, or clayey); stratified [4]	Prismatic; platy [2]	Structureless; single-grained if sandy [0]
Texture (in rooting zone)	Silty or loamy, (or stratified) [4]	Clayey [2]	Sandy [0]
Flooding	Winter through spring [4]	Winter only [2]	None [0] Continuous [Unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [2]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [0]

Continued

Table 9. — *Site Evaluation Guide for PECAN (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [5]	Mixed Coastal Plain and other [3]	Coastal Plain [2]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated < 5 years [6]	Moderate cultivation; cultivated 5-10 years, or open with grass [4][3]	Intensive cultivation; cultivated > 10 years, or open and bare [2][4]
Organic matter (A-horizon)	2% [5]	1-2% [3]	< 1% [0]
Depth of topsoil (A-horizon)	>6″ or no profile development [6]	3-6″ [3]	<3″ [-4]
Soil age	Young, no profile development (Entisols) [3]	Medium, moderate profile development (Inceptisols) [2]	Old, well-developed profile, leached (Alfisols; Ultisols) [1]
pH (in rooting zone)	5.5-7.5 [5]	4.5-5.5 or 7.6-8.5 [5]	< 4.5 or > 8.5 [3]
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty [5]	Prismatic; blocky [2]	Massive (if clayey); platy [0]
Swampiness	Wet in winter only [7]	Wet January-July [3]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [8]	None to 8″ depth [4]	Mottled to surface or gray mineral soil [-1]
Soil color (in rooting zone)	Black, brown, red [8]	Yellow, brownish-gray [4]	Gray [-1]

[1] 115 feet at 50 years maximum S.I ; 70 feet minimum acceptable S.I.

[2] Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

[3] If the soil is sand or loamy sand, then [-4].

[4] If cultural practices included annual fertilization, then [5].

Table 10. — *Site Evaluation Guide for SWEETGUM*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
Factor 1. Physical condition			
Soil depth and presence of artificial or inherent pan	Deep soil ($>$ 4 feet); without pan [6][2]	Medium depth (2-4 feet), or a soil with a plowpan [4]	Shallow soil ($<$ 2 feet), or a soil with an inherent pan [-2]
Texture (in rooting zone)	Medium-textured; silty or loamy [4]	Coarse-textured; sandy [2]	Fine-textured; clayey [1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density $<$ 1.4 g/cc [6]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [4]	Strongly compacted, tight, bulk density $>$ 1.7 g/cc [-2]
Structure (in rooting zone)	Granular; blocky; structureless, single-grained if sandy, massive if loamy or silty [6]	Prismatic; platy [4]	Massive (if clayey); [0]
Past use and present cover	Undisturbed; near-virgin, forest cover [8]	Moderate cultivation; cultivated $<$ 20 years, or open with grass cover [5]	Intensive cultivation; cultivated $>$ 20 years, or open and bare [2]

Continued

Table 10. — *Site Evaluation Guide for SWEETGUM (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
Factor 2. Moisture availability during growing season			
Water table depth	2-6′ [6]	1-2′; 7-10′ [3]	< 1′ [unsuitable]; > 10′ [-3][3]
Artificial or inherent pans	No pans [6]	Plowpan [3]	Inherent pan [-3]
Topographic position	Floodplain or stream bottom [5]	Stream terraces or lower slopes [3]	Upland [-2]
Microsite	Concave; depression, pocket, trough [2]	Level; flat [1]	Convex; ridge, mound [-2]
Structure (in rooting zone)	Granular; blocky; structureless, massive (if silty, loamy, or clayey); stratified [5]	Prismatic; platy [3]	Structureless, single-grained if sandy [-1]
Texture (in rooting zone)	Silty or loamy, (or stratified) [5]	Clayey [2]	Sandy [0]
Flooding	Winter through spring [5]	Winter only [3]	None [0] Continuous [Unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [2]	Moderate cultivation; cultivated < 10 years or open with grass cover [1]	Intensive cultivation; cultivated > 10 years or open and bare [0]

Continued

Table 10. — *Site Evaluation Guide for SWEETGUM (con't)*

Soil-site property	Soil-site condition and relative quality Best	 Medium	 Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [5]	Mixed Coastal Plain and other [4]	Coastal Plain [2]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated < 5 years [5]	Moderate cultivation; cultivated 5-10 years, or open with grass [3]¹	Intensive cultivation; cultivated > 10 years, or open and bare [1]¹
Organic matter (A-horizon)	> 2% [4]	1-2% [2]	< 1% [-2]
Depth of topsoil (A-horizon)	> 6″ or no profile development [5]	3-6″ [2]	<3″ [-3]
Soil age	Young, no profile development (Entisols) [4]	Medium, moderate profile development (Inceptisols) [2]	Old, well-developed profile, leached (Alfisols; Ultisols) [0]
pH (in rooting zone)	5.5-7.5 [1]	4.5-5.5 or 7.6-8.5 [0]	< 4.5 or > 8.5 [-1]
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; blocky; structureless, single-grained if sandy, massive if loamy or silty [8]	Prismatic; platy [4]	Massive (if clayey) [-2]
Swampiness	Wet in winter only [8]	Wet January-July [4]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [7]	None to 8″ depth [5]	Mottled to surface or gray mineral soil [-2]
Soil color (in rooting zone)	Black, brown, red [7]	Yellow, brownish-gray [4]	Gray [2]

120 feet at 50 years maximum S.I.; 75 feet minimum acceptable S.I

Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

If the soil is sand or loamy sand, then [-10].

f cultural practices included annual fertilization, then [4].

Table 11. — *Site Evaluation Guide for SYCAMORE*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [10][2]	Medium depth (2-4 feet), or a soil with a plowpan [5]	Shallow soil (< 2 feet), or a soil with an inherent pan [-5]
Texture (in rooting zone)	Medium-textured; silty or loamy [8]	Coarse-textured; sandy [4]	Fine-textured; clayey [0]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density <1.4 g/cc [8]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [4]	Strongly compacted; tight, bulk density > 1.7 g/cc [-2]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [3]	Prismatic; blocky [1]	Massive (if clayey); platy [-3]
Past use and present cover	Undisturbed; near-virgin, forest cover [3]	Moderate cultivation; cultivated < 20 years, or open with grass cover [1]	Intensive cultivation; cultivated > 20 years, or open and bare [0]

Continued

Table 11. — *Site Evaluation Guide for SYCAMORE (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 2. Moisture availability during growing season		
Water table depth	2-6′ [5]	1-2′; 7-10′ [2]	< 1′ [unsuitable]; > 10′ [-5][3]
Artificial or inherent pans	No pans [5]	Plowpan [2]	Inherent pan [-5]
Topographic position	Floodplain or stream bottom [2]	Stream terraces or lower slopes [1]	Upland [-2]
Microsite	Concave; depression, pocket, trough [2]	Level; flat [1]	Convex; ridge, mound [-2]
Structure (in rooting zone)	Granular; structureless; massive (if silty, loamy, or clayey); stratified [1]	Prismatic; blocky [0]	Structureless, single-grained if sandy; platy [-1]
Texture (in rooting zone)	Silty or loamy, (or stratified) [1]	Clayey [0]	Sandy [-1]
Flooding	Winter through spring [3]	Winter only [1]	None [-5]; Continuous [unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [1]	Moderate cultivation; cultivated < 10 years or open with grass cover [0]	Intensive cultivation; cultivated > 10 years or open and bare [-1]

Continued

Table 11. — *Site Evaluation Guide for SYCAMORE (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 3. Nutrient availability		
Geologic source	Mississippi River, Loess, Blackland [12]	Mixed Coastal Plain and other [8]	Coastal Plain [3]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated < 5 years [10]	Moderate cultivation; cultivated 5-10 years, or open with grass [6][4]	Intensive cultivation; cultivated > 10 years, or open and bare [2][4]
Organic matter (A-horizon)	>2% [6]	1-2% [3]	< 1% [0]
Depth of topsoil (A-horizon)	>6″ or no profile development [6]	3-6″ [2]	<3″ [-4]
Soil age	Young, no profile development (Entisols) [4]	Medium, moderate profile development (Inceptisols) [2]	Old, well-developed profile, leached (Alfisols; Ultisols) [-1]
pH (in rooting zone)	5.5-7.5 [1]	4.5-5.5 or 7.6-8.5 [0]	< 4.5 or > 8.5 [1]
	Factor 4. Aeration		
Soil structure (in rooting zone)	Granular, porous; structureless, single-grained if sandy, massive if loamy or silty) [7]	Prismatic; blocky [4]	Massive (if clayey); platy [-4]
Swampiness	Wet in winter only [10]	Wet January-July [8]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [12]	None to 8″ depth [10]	Mottled to surface or gray mineral soil [-5]
Soil color (in rooting zone)	Black, brown, red [10]	Yellow, brownish-gray [8]	Gray [-5]

[1] 130 feet at 50 years maximum S.I.; 70 feet minimum acceptable S.I.

[2] Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

[3] If the soil is sand or loamy sand, then [-10].

[4] If cultural practices included annual fertilization, then [8].

Table 12. — *Site Evaluation Guide for YELLOW POPLAR*[1]

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [10][2]	Medium depth (2-4 feet), or a soil with a plowpan [4]	Shallow soil (< 2 feet), or a soil with an inherent pan [-5]
Texture (in rooting zone)	Medium-textured; silty or loamy [12]	Coarse-textured; sandy [5]	Fine-textured; clayey [-2]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density 1.4 g/cc [8]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [4]	Strongly compacted; tight, bulk density 1.7 g/cc [-2]
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty [5]	Prismatic; blocky [3]	Massive (if clayey); platy [0]
Past use and present cover	Undisturbed; near-virgin, forest cover [5]	Moderate cultivation; cultivated < 20 years, or open with grass cover [2]	Intensive cultivation; cultivated > 20 years, or open and bare [1]

Continued

Table 12. — *Site Evaluation Guide for YELLOW POPLAR (con't)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 2. Moisture availability during growing season		
Water table depth	2-6′ [5]	1-2′; 7-10′ [3]	< 1′ [unsuitable]; > 10′ [-3][3]
Artificial or inherent pans	No pans [6]	Plowpan [3]	Inherent pan [-5]
Topographic position	Floodplain or stream bottom [6]	Stream terraces or lower slopes [4]	Upland [0]
Microsite	Concave; depression, pocket, trough [3]	Level; flat [2]	Convex; ridge, mound [1]
Structure (in rooting zone)	Granular; blocky; structureless;-massive (if silty, loamy, or clayey); stratified [2]	Prismatic; platy [1]	Structureless; single-grained if sandy [0]
Texture (in rooting zone)	Silty or loamy, (or stratified) [2]	Clayey [1]	Sandy [0]
Flooding	Winter through spring [3]	Winter only [2]	None [-1] Continuous [Unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [3]	Moderate cultivation; cultivated < 10 years or open with grass cover [2]	Intensive cultivation; cultivated > 10 years or open and bare [0]

Continued

Table 12. — *Site Evaluation Guide for YELLOW POPLAR (con't)*

Soil-site property	Soil-site condition and relative quality: Best	Medium	Poor
Factor 3. Nutrient availability			
Geologic source	Mississippi River, Loess, Blackland [4]	Mixed Coastal Plain and other [3]	Coastal Plain [2]
Past use and present cover	Undisturbed; near-virgin forest cover, cultivated < 5 years [4]	Moderate cultivation; cultivated 5-10 years, or open with grass [2][4]	Intensive cultivation; cultivated > 10 years, or open and bare [0][3]
Organic matter (A-horizon)	> 2% [5]	1-2% [3]	< 1% [0]
Depth of topsoil (A-horizon)	>6″ or no profile development [6]	3-6″ [3]	<3″ [-2]
Soil age	Young, no profile development (Entisols) [3]	Medium, moderate profile development (Inceptisols) [2]	Old, well-developed profile, leached (Alfisols; Ultisols) [1]
pH (in rooting zone)	4.5-7.5 [3]	7.6-8.5 [0]	< 4.5 or > 8.5 [-3]
Factor 4. Aeration			
Soil structure (in rooting zone)	Granular, porous; structureless single-grained if sandy, massive if loamy or silty) [8]	Prismatic; blocky [2]	Massive (if clayey); platy [-4]
Swampiness	Wet in winter only [6]	Wet January-July [3]	Waterlogged all year [Unsuitable]
Mottling	None to 18″ depth [8]	None to 8″ depth [4]	Mottled to surface or gray mineral soil [-1]
Soil color (in rooting zone)	Black, brown, red [8]	Yellow, brownish-gray [4]	Gray [-1]

125 feet at 50 years maximum S.I.; 70 feet minimum acceptable S.I.

Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

If the soil is sand or loamy sand, then [-5].

If cultural practices included annual fertilization, then [3].

Table 13 *Expected stand and production data for cottonwood at various ages by site class*

Site index range (Ft @ 30 yrs)	Site class	Thinning	STAND DATA No. trees per acre	Mean ht (ft)[a]	Mean dia (in)	Basal area (ft²)	EXPECTED PRODUCTION PER ACRE VOLUME ft³	Cords[c]	M bm[d] Doyle	Int ¼	DRY MATTER (TONS)[e] Branches	Stems
AT AGE 5 (Before thinning)												
80-90	III (Low)	None	325 ± 20	30 ± 5	4 ± 1	30 ± 5	250 ± 80	3 ± 1	—	—	4 ± 1	4 ± 1
100-110	II (Med)	1/2 BA	325 ± 20	35 ± 5	6 ± 1	65 ± 10	735 ± 205	8 ± 2	—	—	5 ± 1	8 ± 2
120-130	I (High)	1/2 BA	325 ± 20	45 ± 5	7 ± 1	85 ± 10	1505 ± 310	17 ± 3	—	—	7 ± 1	14 ± 3
AT AGE 10 (Before thinning)												
80-90	III (Low)	1/2 BA	310 ± 20	45 ± 5	7 ± 1	90 ± 10	1430 ± 250	16 ± 3	—	—	6 ± 1	14 ± 2
100-110	II (Med)	1/3 BA	155 ± 15	60 ± 5	10 ± 1	85 ± 10	2185 ± 375	24 ± 4	—	—	5 ± 1	18 ± 4
120-130	I (High)	1/3 BA	155 ± 15	80 ± 5	13 ± 2	140 ± 20	4155 ± 565	46 ± 6	—	—	8 ± 1	43 ± 7
AT AGE 15 (Before thinning)												
80-90	III (Low)	1/3 BA	145 ± 15	60 ± 5	9 ± 1	65 ± 5	1450 ± 200	16 ± 3	—	—	4 ± 1	15 ± 3
100-110	II (Med)	1/3 BA	90 ± 15	80 ± 5	13 ± 2	85 ± 10	2510 ± 360	28 ± 4	3 ± 1	6 ± 2	6 ± 1	29 ± 4
120-130	I (High)	1/3 BA	90 ± 15	100 ± 5	16 ± 2	125 ± 15	4470 ± 520	50 ± 6	10 ± 3	16 ± 4	8 ± 1	58 ± 7
AT AGE 20 (Before thinning)												
80-90	III (Low)	None	85 ± 15	70 ± 5	11 ± 2	55 ± 5	1600 ± 250	18 ± 3			4 ± 1	17 ± 3
100-110	II (Med)	None	55 ± 10	90 ± 5	16 ± 2	75 ± 10	2675 ± 390	30 ± 4	6 ± 2	10 ± 3	5 ± 1	30 ± 6
120-130	I (High)	1/3 BA	55 ± 10	110 ± 5	18 ± 2	95 ± 10	4260 ± 530	48 ± 6	11 ± 3	16 ± 4	6 ± 1	50 ± 7
AT AGE 30												
80-90	III (Low)	CC	75 ± 10	85 ± 5	14 ± 2	80 ± 10	2730 ± 450	30 ± 5	5 ± 2	8 ± 2	5 ± 1	31 ± 6
100-110	II (Med)	CC	50 ± 5	105 ± 5	20 ± 2	110 ± 20	4255 ± 585	48 ± 6	15 ± 4	21 ± 5	6 ± 1	51 ± 7
120-130	I (High)	CC	30 ± 5	125 ± 5	28 ± 3	130 ± 25	6125 ± 615	68 ± 7	32 ± 6	38 ± 6	8 ± 1	73 ± 8
NET PRODUCTION AT AGE 30 (Clear-cut @ age 30 plus previous thinnings)												
80-90	III (Low)						3930 ± 640	43 ± 7	5 ± 2	8 ± 2	9 ± 1	43 ± 8
100-110	II (Med)						6190 ± 935	69 ± 10	16 ± 4	23 ± 5	13 ± 2	71 ± 10
120-130	I (High)						11170 ± 1305	124 ± 14	39 ± 8	49 ± 8	19 ± 2	130 ± 15

[a] Dominants and codominants

[b] From Mohn and Krinard's (1971) volume equations for merchantable volume outside bark to a 3½-inch top

[c] Cords ft³ volume 90

[d] From giant tree volume tables (F C 78) for gross tree volume outside bark to a 10-inch top (Grosenbaugh 1954 Putnam *et al* 1960) Remaining tops left on site and not included in ft³ or cord production

[e] From Mueller's (1976) dry matter equations

Table 14. — *Estimated stand and production data for sweetgum and sycamore at age 30 by site class*

Site index range (ft. @ 50 yrs)	STAND DATA				ESTIMATED PRODUCTION PER ACRE[b]			
	No. trees per acre	Mean ht (ft)[a]	Mean dia (in)	Basal area (ft^2)	ft^3	Cords[c]	M bm Doyle	M bm Int. ¼
				SWEETGUM				
75 - 85	145 ± 15	55 ± 5	8 ± 2	50 ± 5	1965 ± 320	20 ± 3	—	—
95 - 105	100 ± 10	70 ± 5	11 ± 2	65 ± 10	3095 ± 470	34 ± 5	—	—
115 - 125	60 ± 5	90 ± 5	15 ± 2	75 ± 15	5585 ± 650	62 ± 7	6 ± 2	9 ± 2
				SYCAMORE				
80 - 90	100 ± 10	60 ± 5	10 ± 2	55 ± 5	2633 ± 430	29 ± 5	—	—
100 - 110	65 ± 5	80 ± 5	14 ± 2	70 ± 10	4147 ± 625	46 ± 7	4 ± 1	7 ± 2
120 - 130	40 ± 5	100 ± 5	19 ± 2	80 ± 15	7485 ± 875	83 ± 10	10 ± 3	14 ± 3

[a] Dominants and codominants

[b] Production estimated as a proportion of cottonwood production based on early growth and development on various sites.

[c] Cords = ft^3 volume ÷ 90

APPENDIX

Explanation of Terms

The explanation of terms is for use with tables 1-12. For terms not defined, see *Glossary of Soil Science Terms* (1975) or *Soil Survey Manual* (1951).

Compaction: Any process by which the soil grains are rearranged to decrease void or air spaces and bring them into closer contact with one another. In most cases, the process is caused by traffic or other artificial means. Some clayey. non-montimorillionitic soils are described as being firm or tight in regard to compaction. This compaction, resulting from a natural alinement of fine particles, occurs because of a lack of shrinking and swelling.

Depth of Topsoil or A-Horizon: Depth of surface soil or depth to B-horizon. Topsoil depth can be distinguished by a rather abrupt change in soil color or texture. Topsoil is ordinarily darker in color and coarser in texture than subsoil.

Geologic Source: Geologic origin of the soil or the physiographic area in which the soil occurs. Soils in the Mississippi River, Loess, and Blackland areas are generally high in native fertility. Coastal Plain soils are relatively low in native fertility and have low pH (< 5.5); when mixed with other geologic sources that are more fertile, they usually have a pH higher than 5.5.

Mottling: Spots or blotches of different color (normally gray, yellow, or light brown) interspersed within the dominant color of the soil. Mottling is usually caused by poor internal drainage and poor aeration.

Organic Matter The organic fraction of the soil: includes plant and animal residues at various stages of decomposition. Soils with high organic matter content are generally dark in color and have visible humus particles, while soils with low organic matter content are light colored.

Pans: Layers in the soil that are strongly compacted, hardened, or very high in clay content. Pans often restrict root penetration and vertica movement of soil water.

Artificial Pans (Plowpans or Pressure Pans) A subsurface soil layer that is compacted as a result of normal tillage operations or other artificial means. These pans can normally be detected as resistance to downward movement of a soil auger and by the tightly compacted, dense, and often dry soil condition.

Inherent or Genetic Pans A natural subsurface soil layer that is harder or more cemented or brittle than the soil above and below it. Often called claypan or fragipan.

Soil Depth: The depth or thickness of soil that can be easily permeated by tree roots and water. Soil depth is commonly controlled by artificial or inherent pans, rock, or stagnate water tables.

Soil Structure: The combination or arrangement of primary soil particles in units or aggregations. These units are often arranged in the profile so that they give a distinctive characteristic pattern. Some common classes of soil structure are: granular, blocky, platy, prismatic, and structureless (single-grained or massive). Detailed descriptions of these structural classes and how to recognize them are given in most Soils textbooks.

Soil Texture: The relative proportions of various size groups of individual soil particles in a mass of soil. Specifically, it refers to the proportions of clay, silt, and sand below 2 mm in diameter.

Water Table Depth: The average depth to a non-stagnant "true" water table during the growing season. Water table depth can often be determined by soil boring to free water or by observing free water elevations in nearby streams, lakes, ponds, etc., in relation to the elevation of the site. For impervious (clayey) soils or soils with pans, the presence of a perched water table during the growing season will tend to improve available moisture. Therefore for these conditions, select the medium category for moisture availability even though a "true" water table occurs at depths $>$ 10 feet.

BAKER, JAMES B. and W. M. BROADFOOT.

1979. A practical field method of site evaluation for commercially important southern hardwoods. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-26, 51 p. South For. Exp. Stn., New Orleans, La.

A new method of evaluating sites for planted cottonwood, sweetgum, sycamore, green ash, hackberry, sugarberry, pecan, yellow poplar and Nuttall, water, willow, swamp chestnut, Shumard and cherrybark oaks is presented.

Additional keywords: Site index, soil properties, *Populus deltoides, Liquidambar styraciflua, Platanus occidentalis, Fraxinus pennsylvanica, Celtis occidentalis, C. laevigata, Carya illinoensis, Liriodendron tulipifera, Q. nuttallii, Q. nigra, Q. phellos, Q. michauxii, Q. shumardii, Quercus falcata* var. *pagodaefolia.*

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TREES
FOR URBAN USE
N PUERTO RICO
AND THE VIRGIN
SLANDS

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Summary

Forty-six tree species useful for shade and ornament in Puerto Rico and the Virgin Islands are described and illustrated. Information is also provided about planting, maintenance, and appropriate use of trees in urban areas.

Acknowledgments

I thank the following for their help: Terry Tenold of the Caribbean National Forest for preparing original drawings; Prof. Roy O. Woodbury for help with identification, nomenclature, and characteristics of the various species; and Dr. Luis F. Martorell for information on insects, diseases, and other problems.

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Introduction

Te increasing urbanization of our society means that more and more ple are isolated from nature. Trees can help make urban areas more sant and liveable by introducing diversity, greenness, and beauty into therwise monotonous scene of buildings and pavement. Trees with cful flowers or foliage add extra attractiveness.

Tes also affect the physical environment. In the tropics, where there is around warmth and sunshine, they help reduce temperatures by ding shade and by intercepting, absorbing, and reflecting solar ition. Also, they function as natural air-conditioners by evaporating tr from their leaves through the process of transpiration. A single, large llwatered city tree can transpire 100 gallons (about 380 liters) of water in e day, producing the cooling effect of five average room air-conditioners ing 20 hours a day. A single tree standing alone will not affect the overall rrundings much, but groups or belts of trees or many trees scattered oghout a neighborhood can be quite effective.

Tes may also help reduce air pollution. Leaves can absorb gaseous llants and can physically trap particulates on their surfaces, especially if rfces are hairy, spiny, or waxy. Twigs, branches, and stems can also ecept particulates. High concentrations of pollutants can damage and e kill trees, although species and even individuals within a species vary hir tolerance of pollutants. Trees that are particularly sensitive could be e as early warnings of high pollution levels.

Tres and shrubs serve as screens to help insure privacy for house and rcn. In properly designed belts they can decrease the force of the wind d educe noise levels from highways and other sources. Even individual e if strategically placed around a house, can provide relief from noise d om annoying lights at night.

Tres and other vegetation also provide shelter for birds and other wildlife at ould otherwise not be found within the city. Patches and belts of vegetation serve as access routes allowing wildlife to penetrate into urban areas far from their natural habitat.

The benefits of trees in urban settings are greatest when good judgment is used in their location, selection, and care. The purpose of this booklet is to inform urban dwellers in Puerto Rico and the Virgin Islands about where to plant, what species to choose, and how to assure lasting benefits by good tree care. Forty-six of the most desirable trees for this region are reviewed in detail. Species included have been limited to those that are widely used and known to be adapted. Twenty-one less suitable or less adaptable species and their limitations, are mentioned briefly in the Appendix. Fruit trees have not been included unless they are equally useful for shade or ornament Successful culture of citrus and other trees for their fruit involves special techniques beyond the scope of this booklet. If you are interested in fruit trees, contact the local office of the Agricultural Extension Service.

Additional help on urban tree problems can be obtained through the Division of Forestry of the Puerto Rico Department of Natural Resources the Forestry Program of the Virgin Islands Department of Agriculture, the Agricultural Extension Service, and commercial nurseries.

Where to Plant

The first thing to consider when planning for trees in your yard is the amount of space available. The size of your lot and the placement of the house on it limit the number and size of trees you can use. Figures 1 through 8 show some sample lots, house locations, and placement of trees.

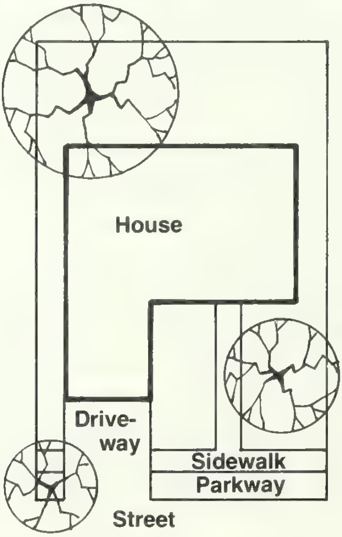


Figure 1.—Small lot with two small trees in front, larger one in back.

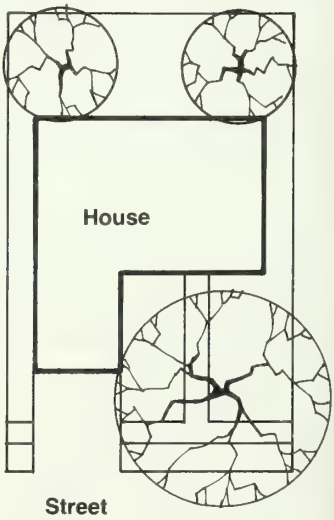
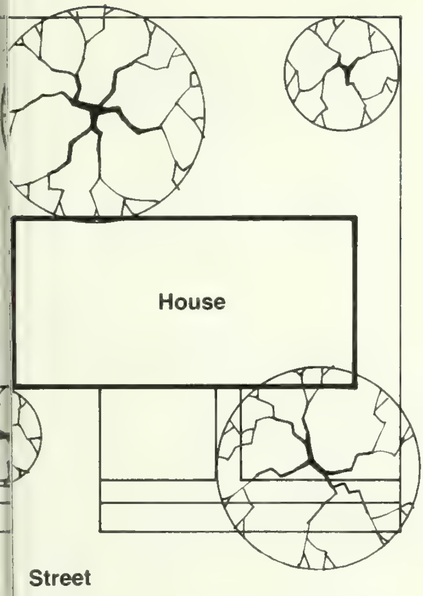


Figure 2.—Small lot with medium tree in front, two small ones in back.



igure 3.—Medium lot with house toward front.

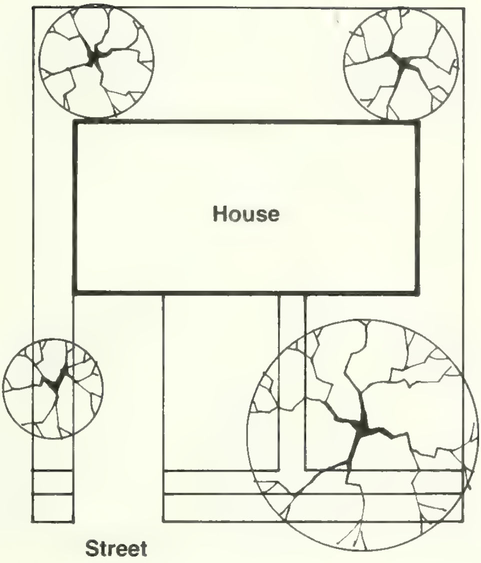


Figure 4.—Medium lot with house toward back.

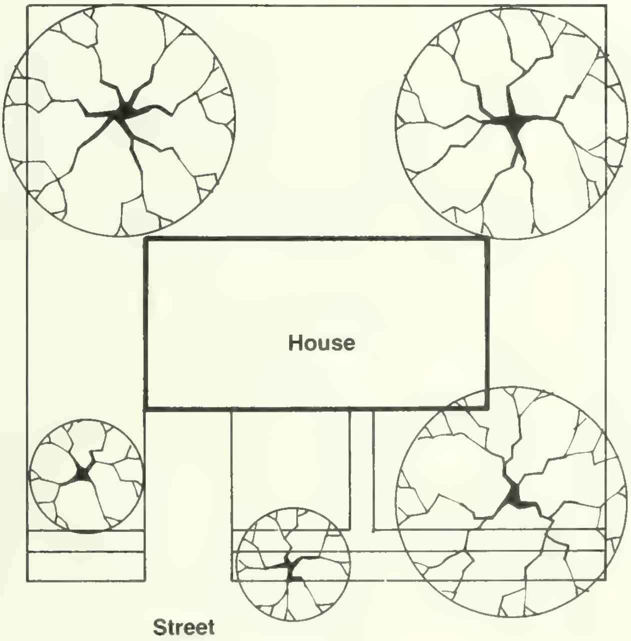


Figure 5.—Large lot with house in center.

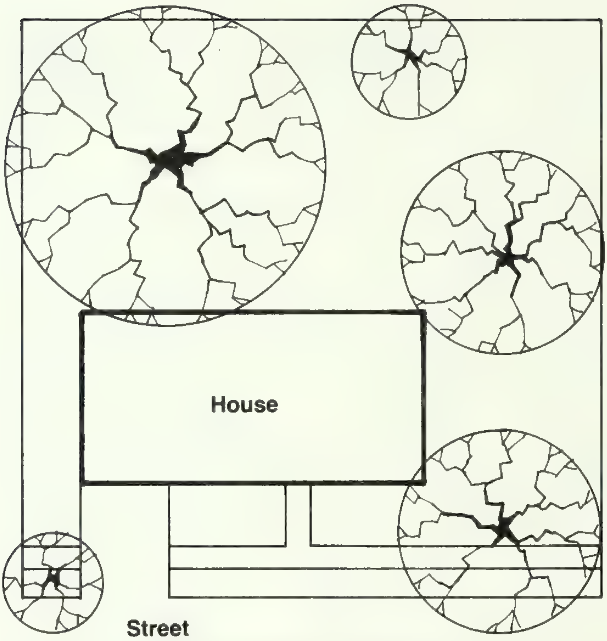


Figure 6.—Large lot with house toward front, leaving space for large tree in back.

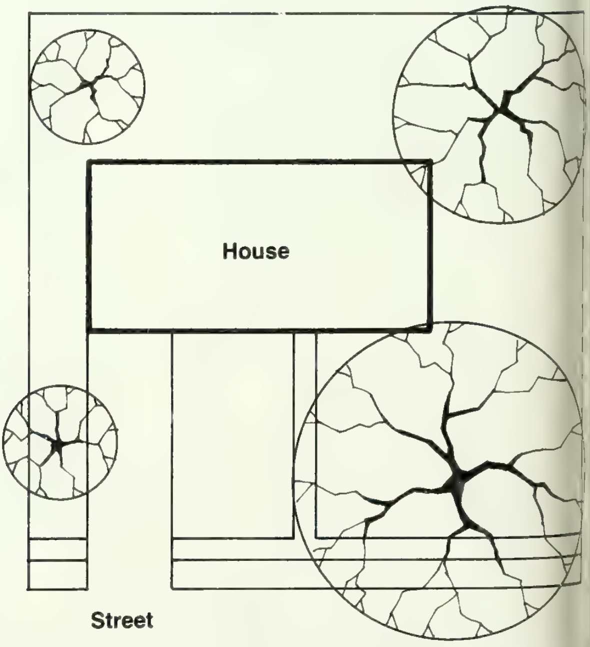


Figure 7.—Large lot with house toward back, large tree in one front corner

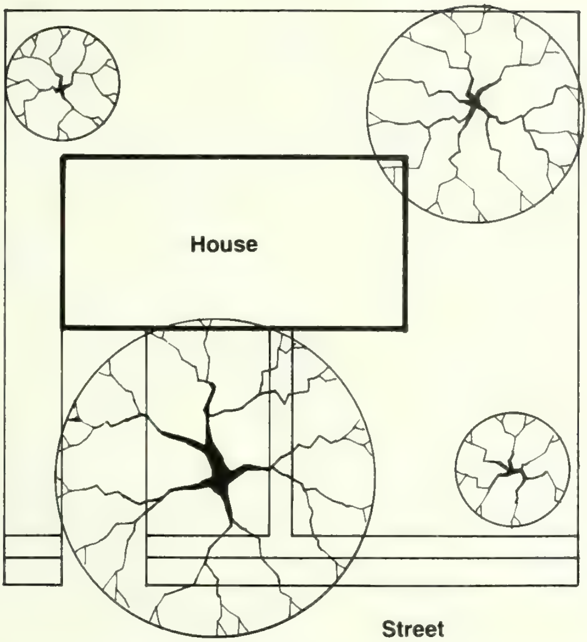


Figure 8.—Large lot with house toward back, large tree between entrance walk and driveway.

ext consider the orientation of your house and lot. An example is shown gure 9, although most lots will not be oriented so perfectly to compass ctions. What are the factors you want to modify? The hottest sun comes m the southwest in the afternoon, so make sure the trees you plant here shade your window, patio, or garden area. Of course, you may also have as you want to shade from the morning sun. Breezes, except in the rior of islands, usually come from the ocean in the day and the mountains night, and you probably will not want to block these from cooling your se (fig. 10). However, you may want trees to serve as a screen or dbreak for protection near the ocean, to block out a highway or ectionable view, or to provide privacy for family areas of the garden. Bear ind also that trees are the major and most permanent features of your den, but that you will also have lawn, flowers, ground covers, and shrubs achieve the overall effect you want.

Overhead wires, underground utilities, and the characteristics of the lot lf limit where you can plant. Overhead wires restrict the size of the trees t can be planted underneath or near them. Trees should not ordinarily be nted near underground utilities because if digging for repairs is needed trees may be damaged. Also, roots can damage underground pipes.

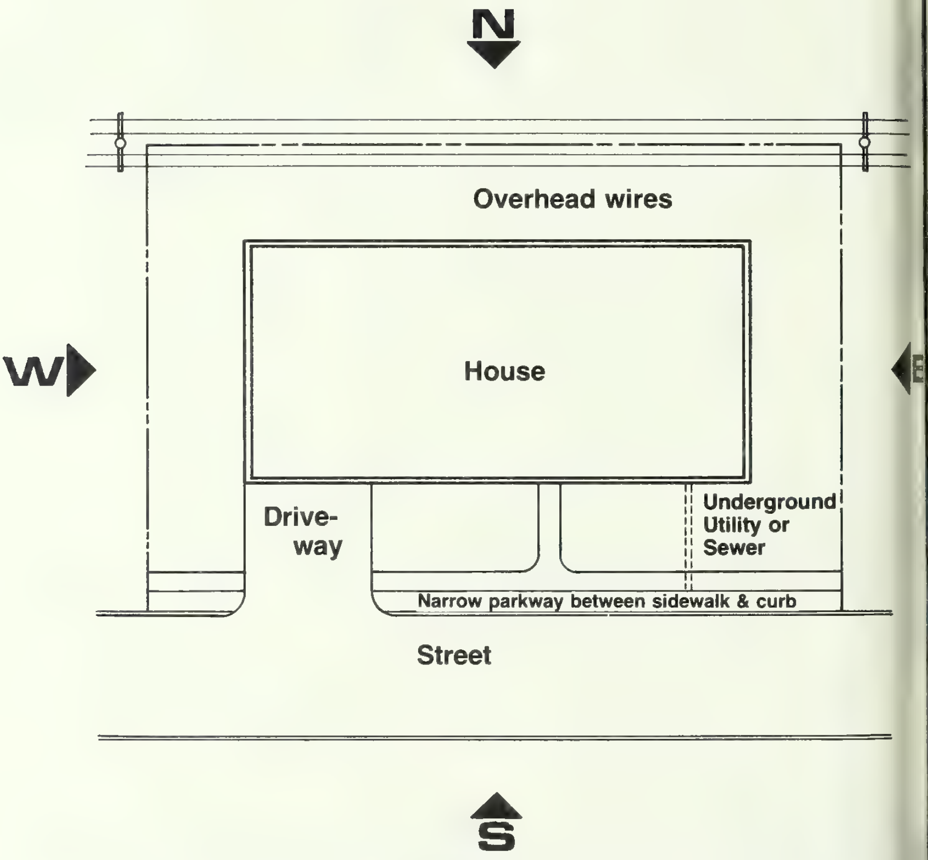


Figure 9.—Typical lot with compass directions and limiting factors indicated.

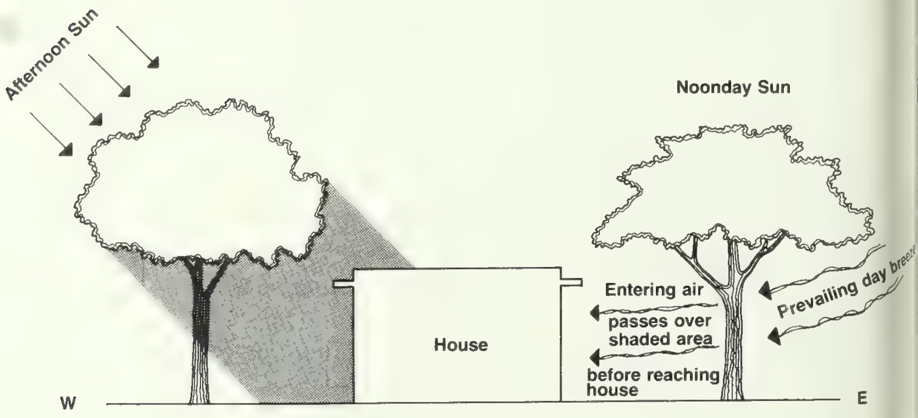


Figure 10.—Tree on left provides shade from afternoon sun. Tree on right is pruned permitting breeze to pass beneath crown.

rass, flowers, ground covers, or shrubs in such areas. Confined areas, as a narrow unpaved parkway between the sidewalk and curb, are le only for trees whose trunk and roots are not likely to cause damage. 11 illustrates some common problems that should be avoided.

acing of trees is also determined by size. Trees that will be large at ity can be spaced closely for quick early coverage. As they grow , however, you will need to thin out the poorer trees to leave enough for the remaining ones.

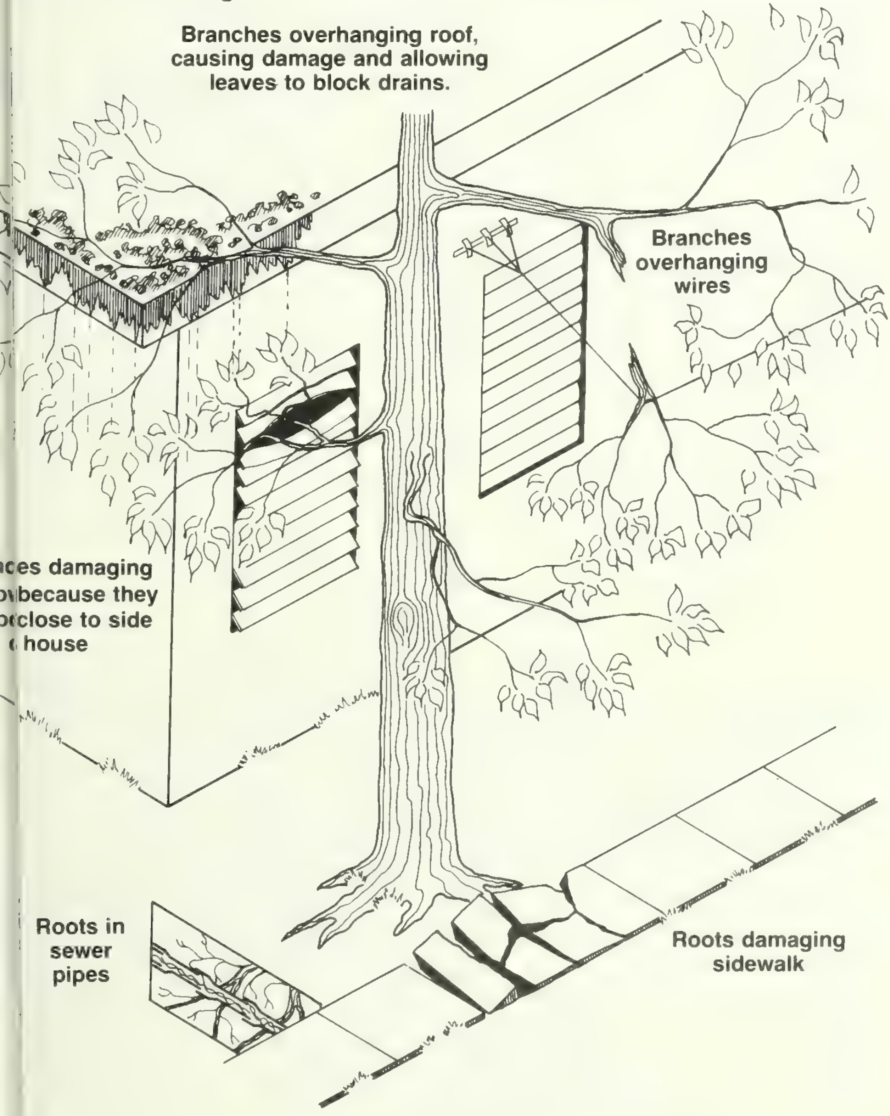

Branches overhanging roof, causing damage and allowing leaves to block drains.
Branches overhanging wires
ces damaging because they close to side house
Roots in sewer pipes
Roots damaging sidewalk

Figure 11.—Results of poor planning in tree location.

Trees along property lines should be located with consideration for the effect on neighboring yards. If you plant trees (and other vegetation) close t carports or driveways, be sure they will not block the view of drivers entering or leaving. Locate trees along the street so they do not interfere with street lighting, and do not plant so close to intersections that trees obscure approaching cross traffic.

Planting trees can be a community as well as an individual project. Trees can screen traffic along through roads and limited-access highways not directly bordered by trees in residential areas. The minimum setback from the roadway is prescribed by regulations of the Federal Highway Administration and local agencies, but within these limitations trees can relieve monotony if long stretches are not planted to only one species. Also trees can highlight interesting features or views by leading up to or framing them. Planting a stand of flowering or ornamental trees in the open spaces within cloverleaf intersections adds visual variety and reduces maintenance; smaller trees and shrubs can screen opposing lanes of traff (fig. 12). Here again, regulations govern the minimum setback from the ramp pavement, and trees should not be located where they will conceal merging traffic.

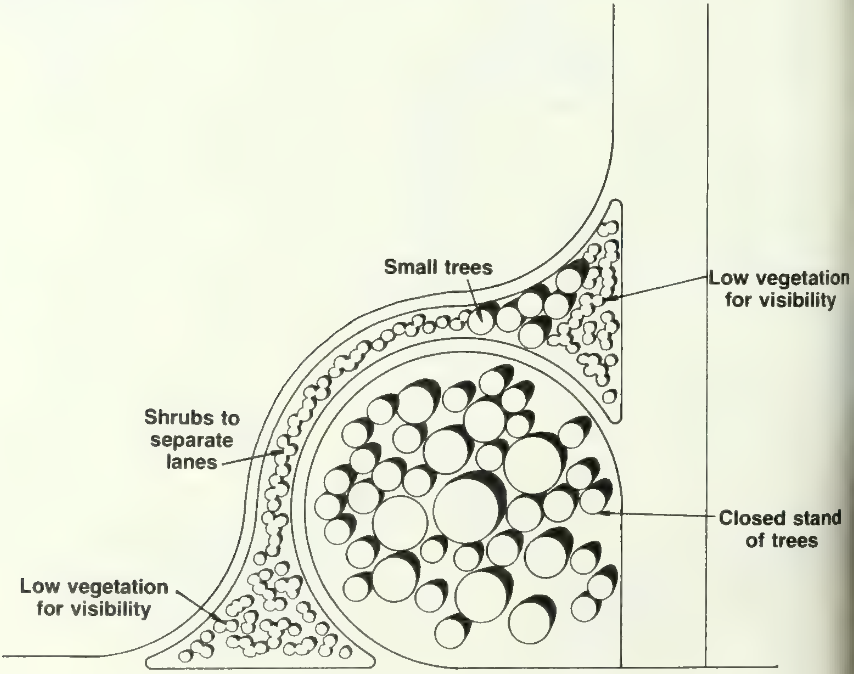


Figure 12.—One quarter of a clover-leaf intersection planted with trees and shrubs.

ound public buildings and in parks and plazas more and larger trees can sed than fit around most homes. Trees can guide traffic to the entrance, en the parking area and part of the building, and provide framing and scaping (fig. 13). In parks and plazas, trees can create a restful, try-like atmosphere in the midst of the city.

es can also be used to form greenbelts along streams or between visions, to provide shelter for wildlife, and to bring the feeling of the t into the urban area. They could be used, within the limitations of air rules, as multi-row belts around the edges of airports to screen the noise and movement of aircraft from the surrounding neighborhoods (fig. 14). And they can be used in beach areas to provide protection from wind and salt spray, to furnish shade and relief from glare for beachgoers, and to create the tropical effect so commonly associated with Puerto Rico and the Virgin Islands.

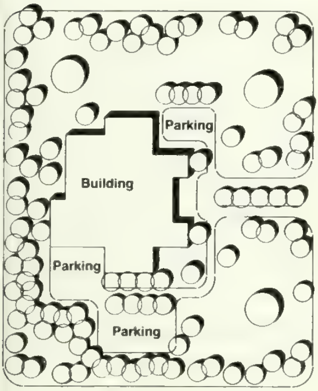
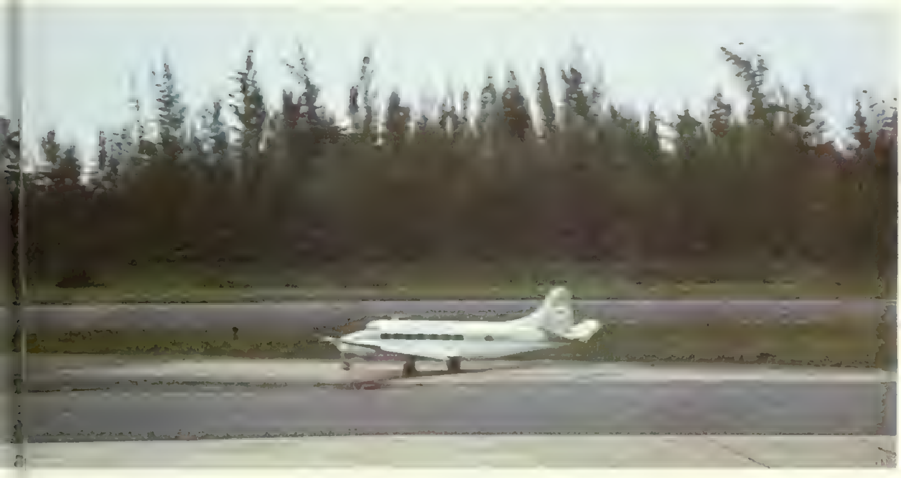


Figure 13.—Use of trees around public building.

Figure 14—This belt of casuarina planted beyond edge of airstrip screens adjacent area from air traffic.



What to Plant

Once you have decided where you want your trees, you need to conside the reason for planting each one. Is it for shade, screening, to frame the house or set off a view, to provide color with a flowering tree, or simply to have something green? The same tree can serve more than one functio but be sure that the species you select will fulfill your purpose.

The adaptability of the species is a first consideration. Some species wi grow well under widely varying conditions, but others do best only unde specialized conditions. For example, some will grow in dry areas, or on rock or sandy soil; others, however, need good soil with adequate moisture an good drainage. Conditions can be modified, such as by supplying extra water or fertilizer, but planting a species adapted to your situation in the firs place is easier. Also some conditions such as poor drainage or salt spra close to the ocean may be expensive or impossible to modify.

The ultimate size and growth habit must also be considered. The mature size of the tree should fit its location. A species with a large spreading crown should not be planted where it will interfere with overhead wires or nearb buildings (fig. 15). If it cannot be given enough room, smaller species shoul be chosen. The type of foliage influences other vegetation to be plante beneath the tree, because many grasses, flowers, and shrubs will not gro well under trees with dense evergreen crowns. The tree species planted an the underplanting should be compatible. If a lawn or other shade-intoleran vegetation is desired, use trees that cast only light shade. Or if a dense-crowned tree is planted, use a shade-tolerant ground cover.

You should also consider the tree's rooting habit. All trees have some roots near the surface, where most nutrients are available. But in some species these roots grow quite large on the surface of the ground and ma

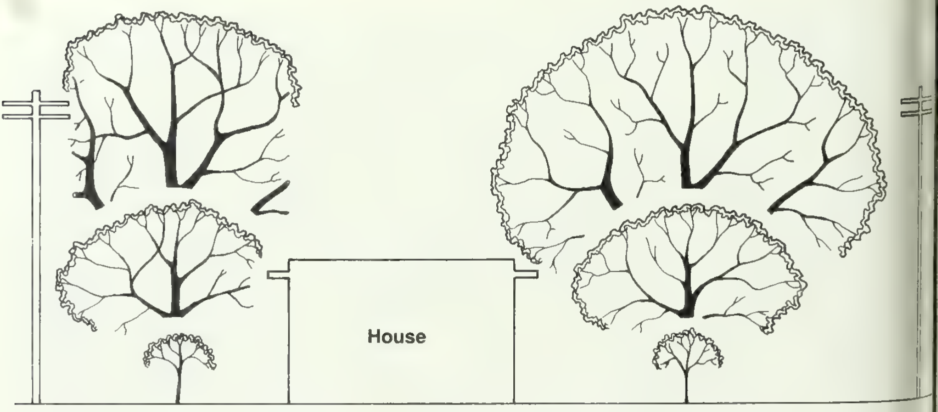


Figure 15.—Tree on left, although apparently with adequate room when small, will be too close to house and wires as matures. Tree on right has adequate room for mature size.

ge sidewalks, driveways, other improvements, and even the
ations of buildings. If a tree of this type is planted, it should be in a large
where roots are free to develop without interfering with structures or
plantings. Also, the roots of certain species are known to grow into and
ewer and other water lines, so do not plant these species near storm or
ry sewers, septic systems, leach beds, or any open water pipe.
trees shed leaves, fruit, dead branches, and other parts from time to
Some species shed gradually, and shedding is hardly noticeable. But
s create considerable litter because the leaves are large, because
eaves fall in a short time, or because falling flowers or fruits are messy.
t plant such trees around a formal patio or other garden area that must
pt tidy, or near a swimming pool. Also, trees that will overhang a
vay or other parking area should not have sap or fruit that stains cars.
ne trees have thorns or spines, irritating or poisonous sap, or
nous fruits, seeds, or leaves. These species should not ordinarily be
d, especially where there are small children, unless they are planted
afe out-of-the-way place. For some situations such species may be
n because of specific attributes of growth or appearance, but this
d be done with full knowledge of the potential hazard they represent.
ricanes and high winds must be considered in the Caribbean area. If
lant species that are particularly susceptible to wind throw or
age, place them where their loss will not cause any major damage.
ee intended to frame the house should not be so large that it
etely dwarfs the building. One planted to provide color should
ement the overall decor. If you want to set off a view, plant species that
ame the view but not intrude into it. If the tree itself is to be the focal
choose a species that will draw attention because of its shape or
display.
ne trees are most effective when more than one is used at a time. For
ple, casuarina and coconut give a maximum tropical effect when
d in groups along the beach. And the full stately effect of the Puerto
oyalpalm is obtained when a row of them is planted along a street,
or border. Planting of trees along streets is usually most effective
the same species is used along a section, giving an impression of
and planning. But planting large areas with a single species is risky,
se an insect or disease could cause catastrophic losses. A possible
n is to plant the same species along one block of a street, alternating
ore or less equal-length sections of several to many other species.

Establishing and Caring for Your Trees

Selecting Stock for Planting

Most readers probably will obtain their planting stock from a nursery. Nursery stock is usually available either as bare-root or as container-grown plants. Bare-root means that the plant has been dug up and all the soil removed from the roots so it can be handled and transported easily. Some roots are destroyed in the process, and those that remain must be carefully protected from drying and breakage. Bare-root plants are often used for large-scale forest plantings, but not so often for ornamental plants that are individually more valuable.

Container-grown plants are raised in cans, plastic pots, polythene bags, or similar containers. The tree is carefully removed from the container and planted with the roots and soil intact. The tree is not subjected to the shock of having its roots disturbed and removed from the soil, so planting may be more successful even during dry weather.

Many species can be propagated vegetatively, by producing a new plant from a branch or root of an existing one. Vegetative propagation is the only way to reproduce many horticultural varieties such as particular growth forms, flowering types, and fruit that will not come true from seed. Methods of vegetative propagation are shoot and root cuttings, grafting and budding, layering, and inarching. The usual method of propagation is mentioned for each species in the individual descriptions. If you are interested in more information on vegetative methods, consult a book such as Hartmann and Kester (1975).

Planting

First, clear all vegetation in a circle at least 6 inches (15 cm) wider on each side than the diameter of the planting hole you plan to dig. The planting hole itself should be about 2 feet (60 cm) wider and 6 inches (15 cm) deeper than the root mass of the tree. Also break up the soil at the bottom of the hole so roots can penetrate it more easily (fig. 16). Save the soil you remove and mix it with peatmoss, compost, or other organic matter to improve the texture of the soil and make it easier for new roots to grow out from the original root mass. Unless you have heavy clay soil, mix in about one shovelful of organic matter for each shovelful of soil.

If the soil in your garden is heavy, clayey, and sticky, the growing roots will have a hard time penetrating it when they reach the edge of the improved soil in the planting hole. Also, water will drain slowly from the loose soil mixture into the heavier clay, so the soil in the hole may become waterlogged if you water too much. With such soil, you should mix an equa

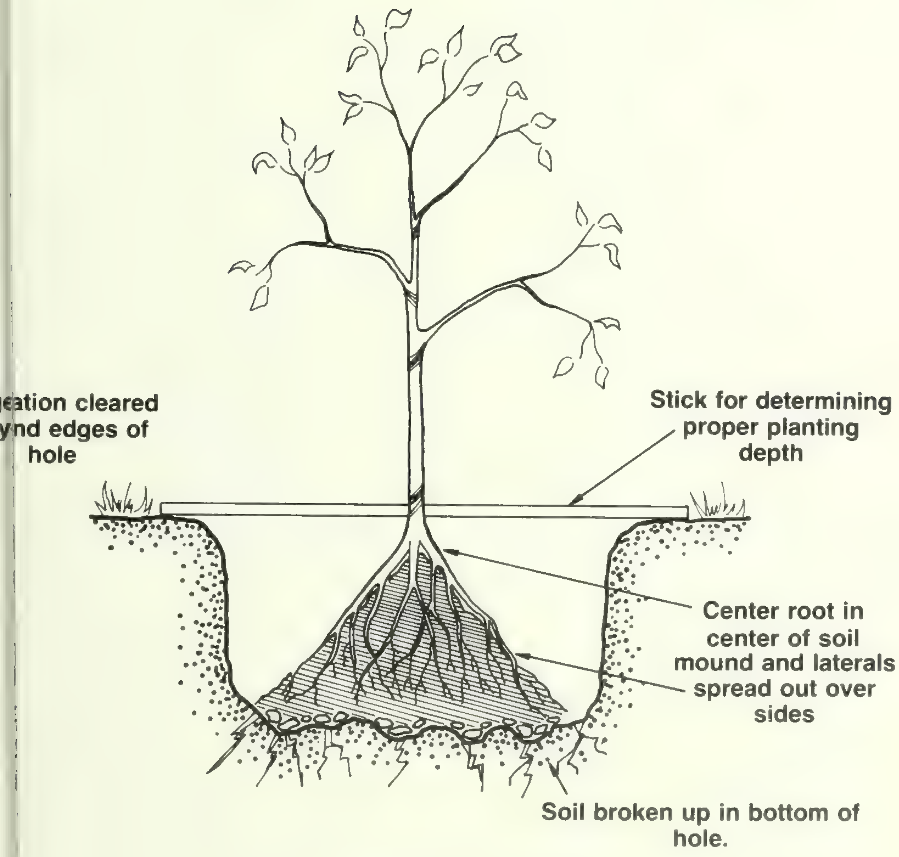


Figure 16.—Planting method for bare-root tree.

oint of organic matter only for the area immediately around the root
ss Then make a transition zone to the heavier soil around the edge of the
e y filling with soil to which you've added only about one shovelful of
aic matter for each three to four shovelfuls of soil. A larger planting hole
ul also give the roots more good soil for their initial growth.

'u enough of the prepared soil mixture into the bottom of the hole to raise
rot mass so the tree will be at the same depth in the ground as it was in
c ntainer, or in the soil in the nursery. A straight stick or tool handle
ce across the top of the hole will make it easy to determine the proper
th (fig. 16). For a bare-root tree, look for a distinct color change in the
k w on the trunk just above the roots. This color change marks the
ne soil level.

th tree is bare-root, the roots should be placed in a pail of water or kept
erd with moist peatmoss or other material until the moment of planting.

Put the central root straight down through the middle of the mound of soil in the hole, and carefully arrange the lateral roots so they are naturally spread out over the mound in the hole (fig. 16). Cut off broken or damaged roots just inside the break. Then fill in about two-thirds of the prepared soil mixture, carefully distributing it around the roots. Thoroughly soak the soil to eliminate air pockets and get complete contact between soil and roots. When the water has drained away, fill in the rest of the soil and water again.

If the tree is container-grown, carefully remove the container without disturbing the mass of soil and roots. If the container is tapered or has fluted sides, you can probably loosen it by setting the container on its side and rapping the rim sharply several times; the root mass should then slide out easily. If not, or if the container has straight sides, you will have to cut it apart. Using tin snips for cans or plastic pots, make two cuts down opposite sides. Large containers may need three or four cuts. But be very careful with cut cans because the edges are sharp and can inflict a serious cut. Polythene bags can be cut open with a knife. When handling the tree the root mass should always be supported with a hand beneath it or holding the container, not holding only the stem, because the weight of the root mass and growing medium may damage or break the stem or roots.

When the container is removed, you may find that the roots are spiralling around the outside or bottom of the root mass. If so, carefully tease them out and spread them in the planting hole, or cut them back if they are too entangled to be separated. Otherwise they may continue their spiral growth instead of spreading out into the surrounding soil.

Once the tree is out of the container, place it on the soil mound in the planting hole and fill in with the rest of the soil mixture (fig. 17). Then pack the soil firmly around the root mass to make sure there are no air pockets, but don't compact it so hard that air and water can't reach the roots. Finally, water well but do not waterlog the soil, or you may drown the roots.

For both bare-root and container-grown trees, build up a rim of soil around the edge of the planting hole to form a saucer-shaped watering basin (fig. 18). When watering, flood this basin slowly so the water gradually saturates the root zone. On clayey soils or in wet areas, you should make a surface drain through the rim of this basin during the wettest part of the year, so that water doesn't stand in the basin and drown the roots. Covering the bare soil within the basin with a loose mulch helps prevent it from drying out rapidly and also protects it from direct sun and hard rain.

For certain species, as mentioned in the individual descriptions, it is also possible to dig up and plant natural seedlings (wildlings) that have become established at the edge of the forest or under parent trees. To save and protect as much of the root system as possible, you must dig up these wildlings carefully. If you can dig and lift them with a ball of earth around the

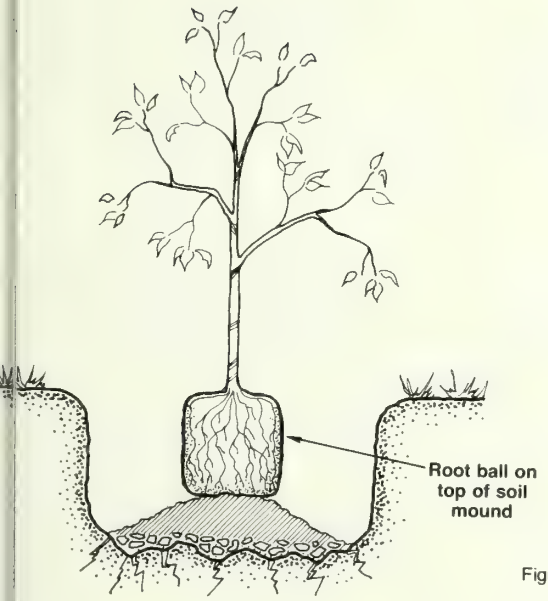


Figure 17.—Planting method for container tree.

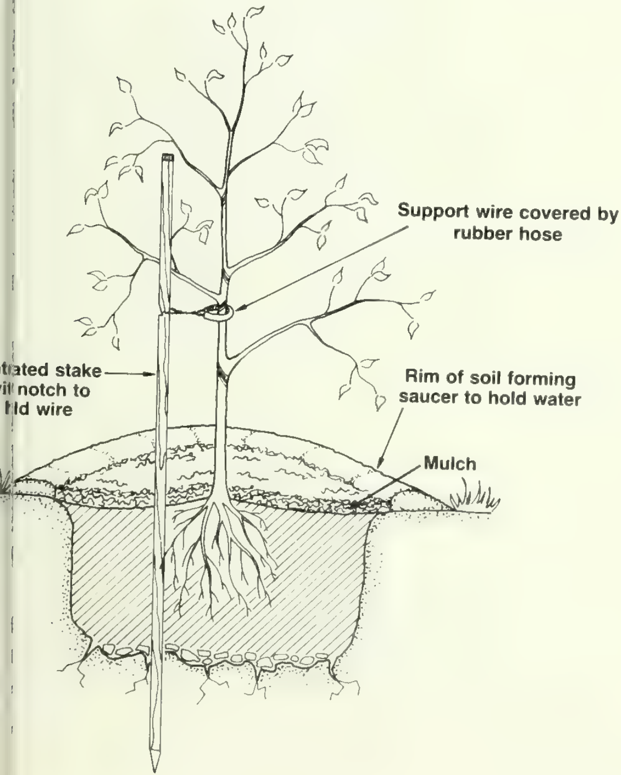

Support wire covered by rubber hose
tated stake
notch to
ld wire
Rim of soil forming saucer to hold water
Mulch

Figure 18.—A tree correctly planted.

roots, plant them like container plants; otherwise, plant them like bare-root plants, but do not let the roots dry out during handling and planting. Tops should be pruned back to reduce water loss until the roots become reestablished (see below). Wildlings, however, are usually inferior to nursery-grown trees because they have not been especially grown to develop strong, transplantable root systems.

Staking

After the tree has been planted, you should stake it for support and protection. For small trees, a single stake on the windward side of the tree is usually enough (fig. 18). Thread the wire around the tree stem through a section of garden hose so that it will not damage the bark. At the stake, place the wire in a notch or otherwise fasten it so it will not slide down the stem The stake should not be treated with preservatives if it is driven into the ground close to the tree's roots, because the chemicals may injure the roots Instead, use either a stake made from naturally durable wood or a length of pipe. For trees taller than about 3 feet (90 cm), more than one stake may be needed. A convenient system is to use three stakes spaced equally around the tree (fig. 19). Adjust the support wires so that the tree stem is held upright and tension is equal on all three sides. Treated stakes can be used here they are driven into the ground outside the area of the planting hole. Inspect the hose-enclosed wires several times a year to make sure the stem has not grown too large for the loops. Also, examine the stakes to be sure they are still solid, especially if untreated wood was used. Staking should be continued until the root system is well established and the trunk is strong enough to hold the crown erect.

If necessary for protection from scratching or gnawing animals, a cylinder of wire fencing or screening at least 2 feet (60 cm) in diameter, slightly sunk into the ground and perhaps supported by a stake, can be placed around the stem.

Pruning Newly Planted Stock

Small container-grown trees usually do not require pruning at planting time unless they have damaged branches. But larger trees, and those planted bare-root, should be pruned or have a number of the leaves removed just after planting. Pruning will reduce water consumption until the root system has reestablished itself. Remove about one-third of the tree's top growth or foliage by thinning out damaged and misshapen branches and any that cross and rub against each other, and by cutting back others such as those that are unusually long. Do not cut back the leader or terminal bud and try to retain the tree's natural shape as much as possible.

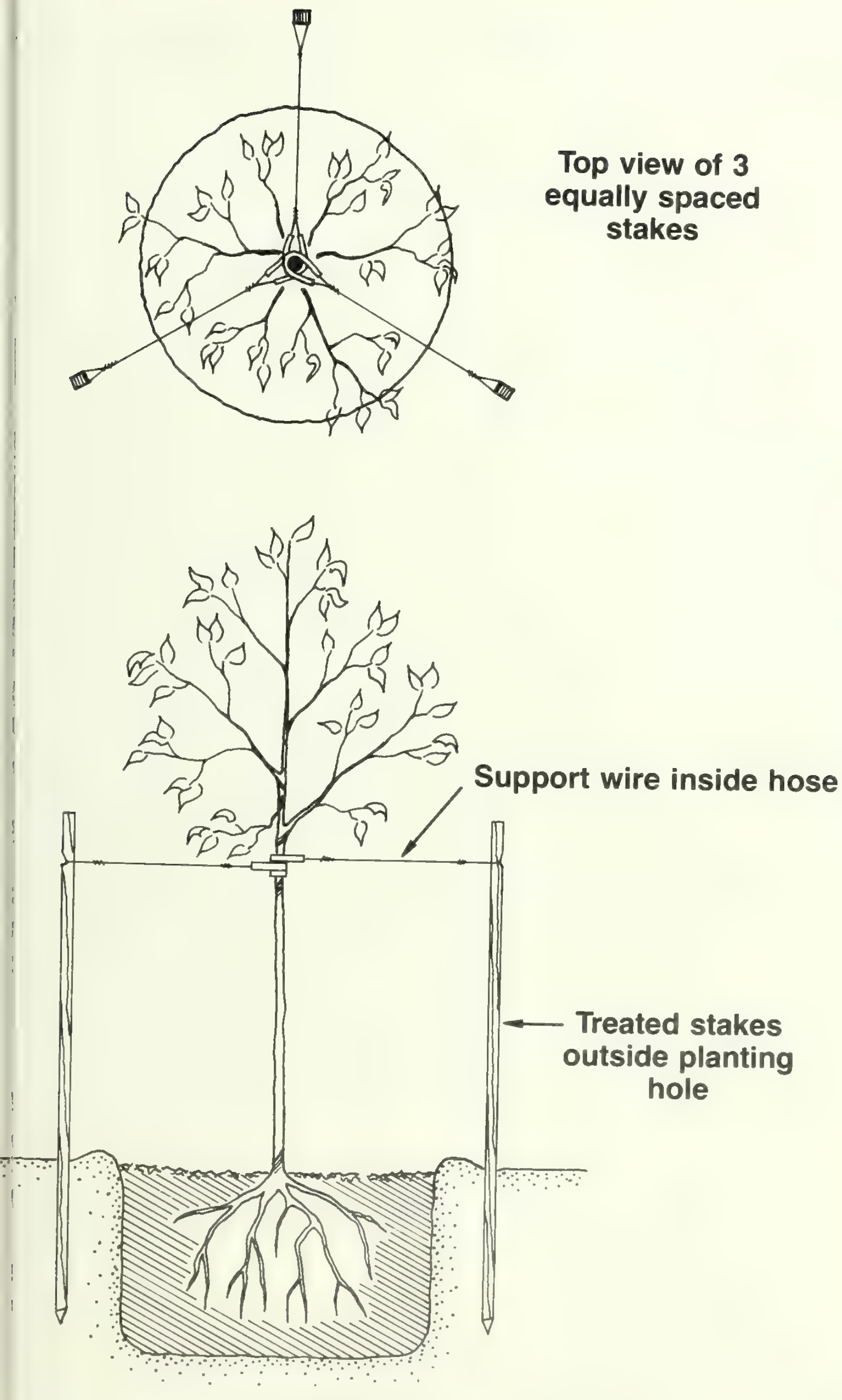

Top view of 3 equally spaced stakes
Support wire inside hose
Treated stakes outside planting hole

Figure 19.—Method of staking tree over 3 feet tall.

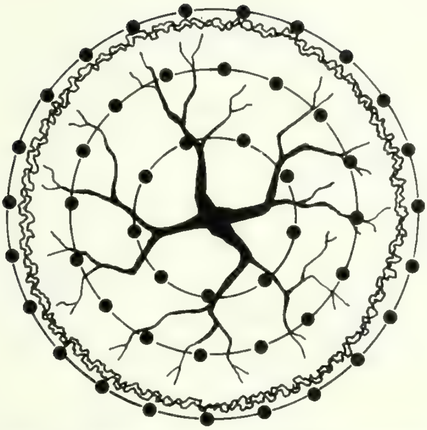
Watering

For about the first 6 months the newly planted tree often needs specia watering. During the rainy season, natural rainfall may be sufficient, but during the dry season and in drought periods extra water will be needed Soak the soil under the tree's crown once or twice a week; trees adapted to dry areas need less moisture than those adapted to wet areas. To be effective, the water must penetrate deeply into the soil, down to and beyond the roots. Frequent light sprinklings only moisten the surface and may result in shallow root development, which makes the tree vulnerable during long droughts. Allow the soil surface to dry between waterings so that air can be absorbed as water drains out of the pore spaces. To allow the roots to develop without competition from the lawn for water or nutrients, keep the area of the planting circle clear of grass for several years. After the tree is well established, it can usually survive with no extra water even during droughts. But for best results it should be watered if the leaves show signs of wilting, especially if it is a tree adapted to wet areas.

Fertilizing

The prepared soil mixture that was placed in the planting hole will furnish an initial supply of nutrients to the young tree. Do not mix ordinary commercial fertilizers with this soil, because they may burn the tender new roots. (Slow release fertilizers are an exception, and can be used if the directions on the label are followed.) However, the tree may need fertilizer periodically to keep it growing well. Ideally, its requirements should be determined by a chemical analysis of the soil, which would show exactly what nutrients are lacking. The local office of the Agricultural Extension Service may be consulted for advice. In the absence of a soil analysis a good general rule to follow, for young trees less than 6 inches (15 cm) in diameter measured at 4½ feet (1.4 m) above the ground, is to use about 1¾ lb (¾ kg) per year of a 15-5-10 (nitrogen-potassium-phosphorus) fertilizer for each inch (2.5 cm) of trunk diameter. For established trees that have a larger diameter about 3½ lbs (1½ kgs) per inch (2.5 cm) of trunk diameter should be used. Apply half the yearly amount about every 6 months. For flowering and fru trees, one of these applications should be made at the beginning of the flowering season for maximum flowering and fruiting.

Fertilizer can be sprinkled lightly and evenly over the ground beneath the tree's crown, starting about 1 foot (30 cm) from the trunk and extending out to the edge of the crown. Water the soil thoroughly afterwards so that the fertilizer begins to dissolve and soak in and does not burn the grass beneath the tree. On lawns, a good way to get the fertilizer down to the tree roots without seriously disturbing the grass is to bore holes into the ground in a pattern as in figure 20. Holes should be drilled with a soil auger, because



20.—Pattern for boring holes to fertilize tree. Circles are 2 ft. (60 cm) apart, and the holes in each circle are also 2 ft. (60 cm) apart.

ning them with a crowbar compacts the soil around the edges. Each es 1 to 2 inches (2.5-5 cm) across and 10 to 15 inches (25-35 cm) deep. stribute the fertilizer more widely, drill holes at an angle instead of aight down. To reduce its concentration and make enough to distribute to the holes, mix the fertilizer with an equal amount of soil or sand. Pour a e of the mixture into each hole; then fill the holes with soil.

Fertilization should not be overdone, because too much fertilizer can build in the soil and harm the tree. The amounts recommended above should be exceeded unless a soil analysis has shown a deficiency. Also, if the e appears to be growing normally with healthy green foliage there is bably no need to fertilize. But trees that are obviously deficient in rients, or that have been weakened by defoliating insects or other mage, should be fertilized promptly.

uning Established Trees

Start pruning early in the life of a tree, eliminating undesirable growth ile leaving only small wounds that will heal quickly. Also, prune gradually that too many branches are not removed at one time and the tree keeps much foliage as possible.

Low branches that obstruct the passage of vehicles or pedestrians along ees or in parking lots, or that hang too low in a garden, should be nced as soon as the tree is tall enough. The ultimate aim is to produce a e that looks as natural as possible (unless formal shaping of a tree apable to such treatment is desired).

Figure 21 illustrates branch terms and some types of undesirable growth. ckers and water sprouts are undesirable, so remove them as soon as y develop. Crotches that are V-shaped split easily and should be cut back

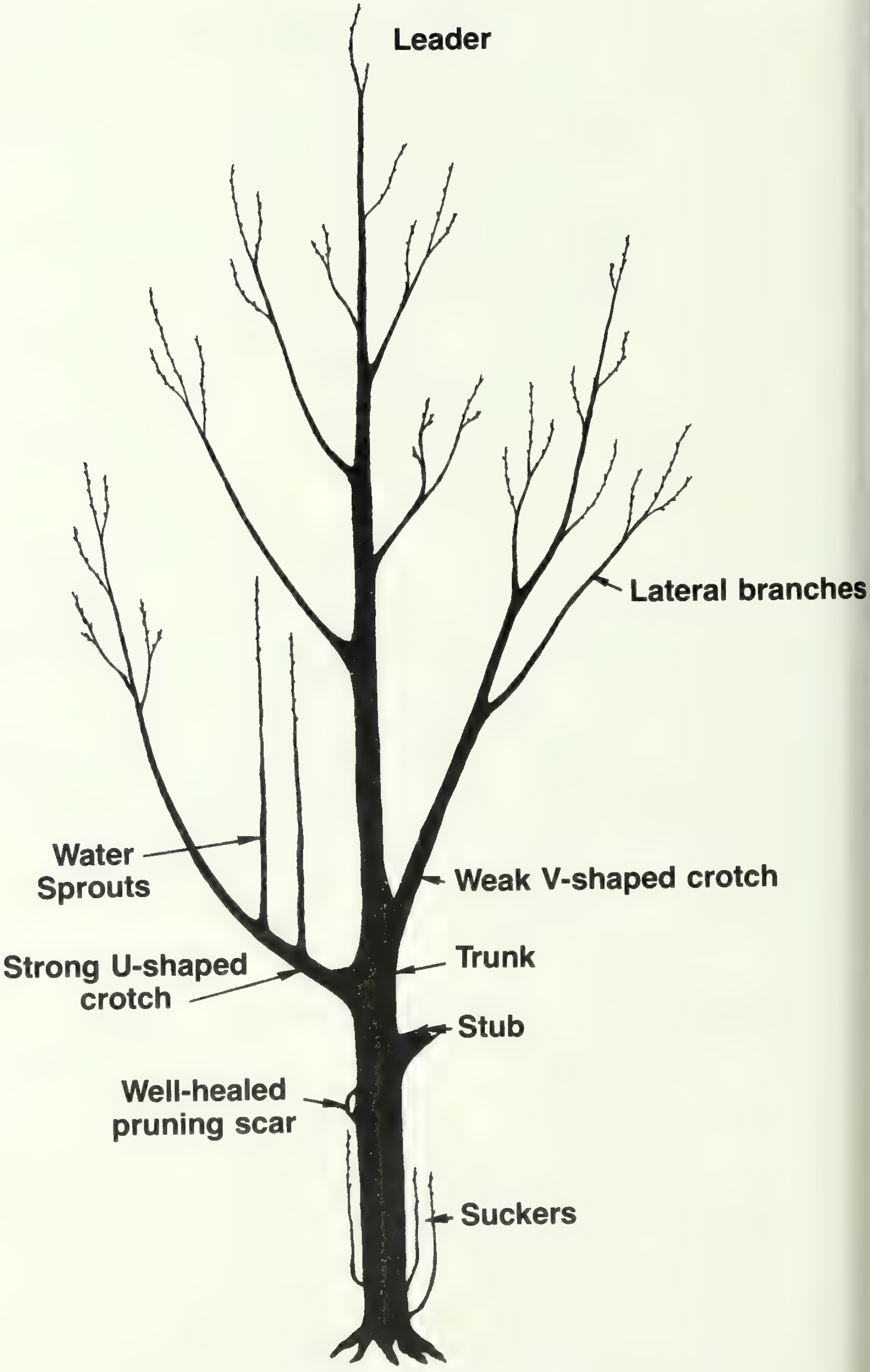


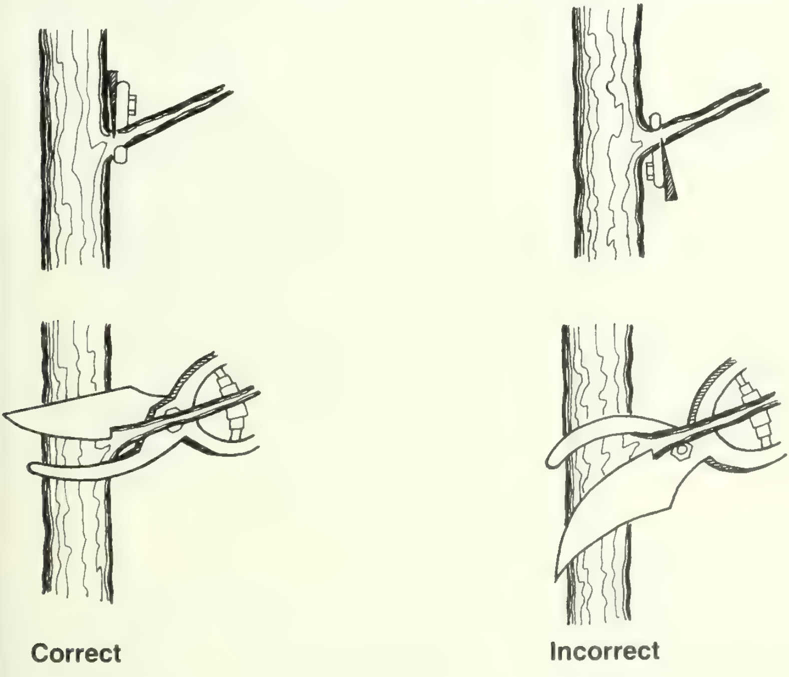
Figure 21.—Branch terms used in pruning.

ne stem when possible. To avoid leaving a stub make the final cut where two sides join solidly. Cut protruding stubs off flush with the stem, ause they usually die back to the stem and serve as an entrance point for ay. Also, remove branches that cross over and rub against another nch or the trunk, because the friction will eventually cause bark damage ugh which decay can enter. Lateral branches that are too long or are ving in the wrong direction can be cut back to just above a healthy bud or de branch that is in the right position for further growth. Do not cut the ler or terminal bud unless you want no further height growth.

netimes, injury to the terminal bud causes multiple leaders to develop. estore dominance and normal development, cut back all but the ngest leader.

ways remove dead, dying, and diseased branches as soon as possible utting back to a healthy crotch or in healthy wood at least 4 inches (10 below any visible signs of infection. To avoid spreading infection when ng in diseased wood, disinfect tools by dipping them into or wiping them 70% alcohol between cuts.

uning tools should be kept sharp and in good condition. To get a good cut when using shears, be sure the cutting edge is next to the stem (fig. For limbs that must be sawed off, cut in three steps as shown in figure 23



22.—Use of pruning shears. Correct method on left with blade next to stem produces clean cut. Incorrect method on right leaves stub.

to prevent bark from tearing down the stem and leaving a large wound wh the branch falls. Large stem wounds can be shaped into an upright oval th will shed water and heal more quickly by carefully cutting in healthy bark w a sharp knife (fig. 24).

Wounds may be painted with a commercial tree-wound dressing that h an asphalt base, or with orange shellac. Do not use ordinary house paint other preparations not specified for plants. However, no dressing will alwa prevent decay. The best results are obtained by pruning properly to lea small wounds in healthy tissue which can heal rapidly.

Avoiding Soil Disturbance

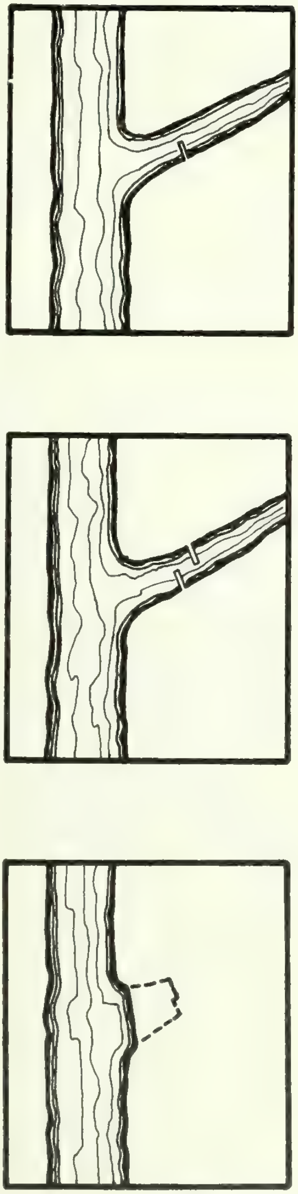
Tree roots need access to moisture and oxygen if the tree is to rem healthy. Changing the soil level above the roots can affect the supply of bo water and air. There is not much problem with the addition of up to 4 inch (10 cm) of soil, provided it is fairly porous and not packed down solidly. thicker covering will require special procedures, including a well around trunk and gravel or drain tile at the original soil level to allow water and ai reach the roots. This is likely to be very expensive and is not always successful, so avoid such changes if possible, or obtain professional advi before undertaking them.

Soil under established trees should not be covered with a pavemen asphalt, concrete, or other impervious material because such covering c off the supply of water and air to the roots. Trees can be planted in openi in such areas, for example in parking lots, but they should be small tr whose root systems can adapt to the confined conditions. Soil compact from trucks or other heavy equipment driving repeatedly over an area is al bad. When such activities are going to take place, fence off the area und the crown of established trees with sturdy barricades if possible, both protect the roots and to prevent physical damage to the trunk from the equipment.

Removing soil from around a tree can also cause problems, because may remove roots that not only keep the tree alive but also help to ancho Again, obtain professional advice for the special procedures needed t safeguard the remainder of the roots. But the likelihood of success is limit if more than a small portion of the root system is affected.

Controlling Insects and Diseases

Problems with insects and diseases are a fact of life when growing plant The best way to avoid these is to choose species that are relatively free fro pests in the area where they are to be planted. The individual spec descriptions give, under **Limitations**, any major insect or disease proble that affect each one.



First cut, from below and at least one-third of the way through the branch, keeps bark from tearing down stem as branch falls.

Second cut, from above and about 1 inch (2.5 cm) further out, severs main part of branch.

Third cut removes stub flush with stem.

Figure 23.—Procedure for cutting large branches.

A areness of the need for conservation and environmental protection
is rought an emphasis on an overall biological approach to pest control.
e ow know that broad spectrum pesticides kill not only the target
ga ism, but many beneficial ones as well, and the long-term result may be
nc e severe problem after the natural enemies that helped keep a pest in

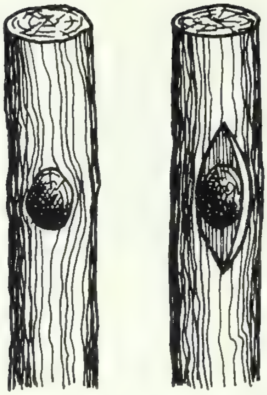


Figure 24.—Wound shaped into upright oval will s water and promote healing.

check have been eliminated. Thus pesticides are just one component of t system, and should be used only when there is no other alternativ prevent extensive damage.

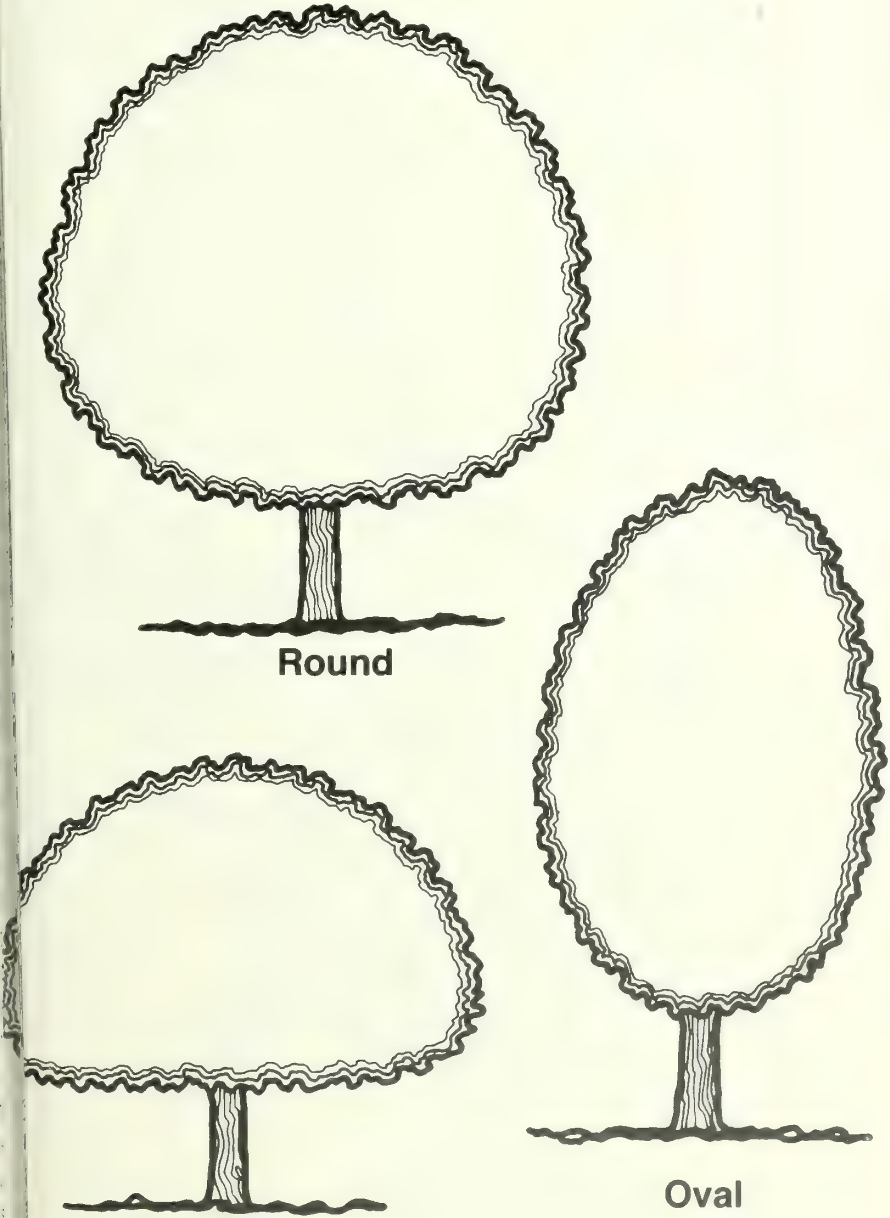
An important part of biological control is prevention. Avoid injury to tru or roots of trees during lawn mowing and other garden work. Keep your ya free of debris where pests can develop, and burn or dispose of infes material promptly. Use a high curb or barricade to protect trees in park lots from damage by cars.

When a problem does occur, the first step is to evaluate whether contro really needed. Many insect or disease attacks come in short-lived wa triggered by weather or season. There is no need to treat a problem that soon go away by itself. Also, it is unrealistic to expect total eradicatio most problems. A few chewed leaves will not bother the tree if the pest is n allowed to build up to epidemic proportions.

If control is necessary, will simple methods do the job? On small tre some insects can be picked off by hand and drowned in kerosene. Oth can be washed off the leaves or stems with a garden hose. A cloth or an toothbrush can be used to clean infested leaves or new growth with so water. Infected twigs and branches can be pruned off and burned otherwise disposed of where they will not serve as sources of fur infection.

When the above methods fail, or for larger trees, a pesticide may needed. If so, try by careful inspection to determine the organism responsible. Or ask the local office of the Agricultural Extension Service help. Then look for a product at a nursery or garden store that is register for that particular organism, and carefully follow the directions. Aft treatment, fertilize and water trees that have been damaged by pes

The ordinary gardener cannot treat large trees. So if you find you h planted a tree that suffers continual pest problems, replace it with a be species before it gets any larger and more difficult to remove.

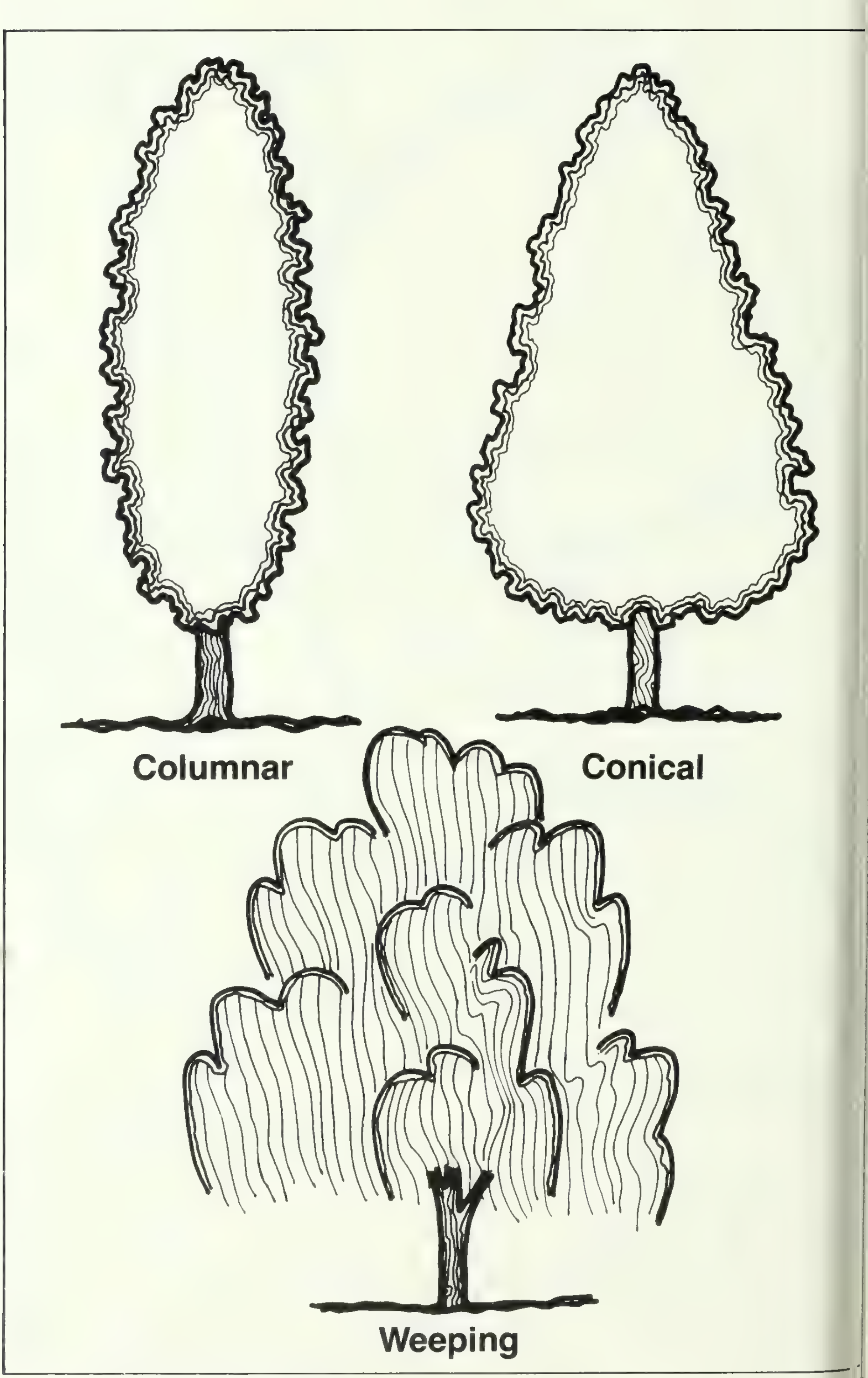


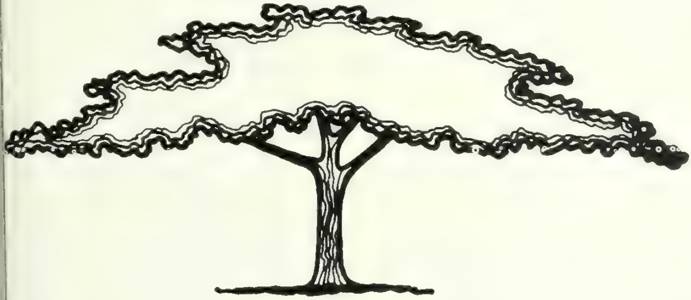
Round

Oval

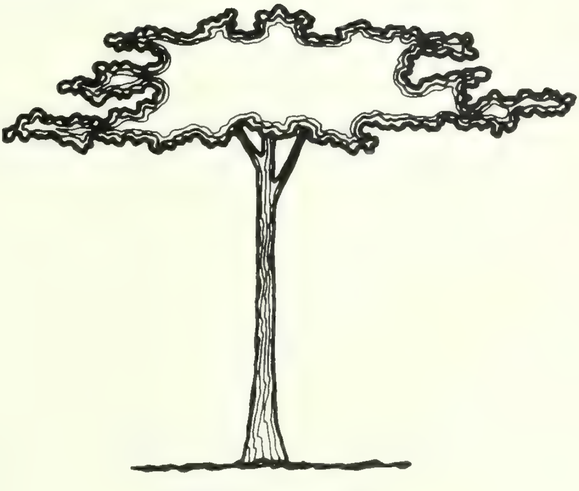
Half round

Typical Tree Crown Forms as Used in Matrix
on Page 30-33

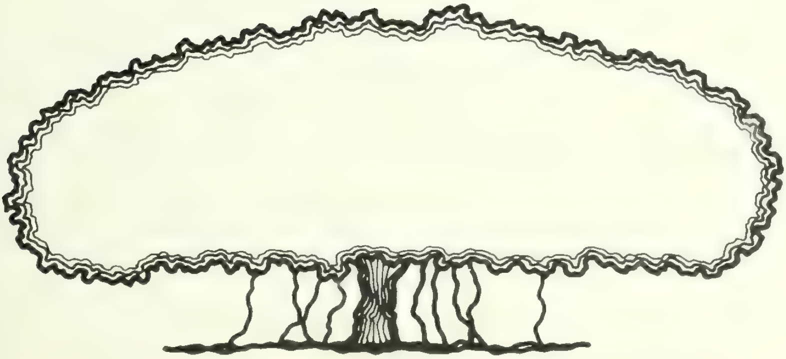

Columnar
Conical
Weeping



Umbrella



Flat-topped



Banyan

Notes for Matrix and Species Descriptions

The matrix on the next several pages lists the species in alphabeti order by scientific name and briefly indicates size, adaptability, and speci features. A section of one-page descriptions with illustrations for ea species follows. Use the matrix to identify one or more species that seem be adapted to your situation, then turn to the descriptions to make a defin selection. If you are interested in a particular species for which you kn only the common name, look in the index where the common as well as t scientific names of all species are listed with the page number on whic each is described or mentioned.

Nomenclature follows Little and Wadsworth (1964) and Little, Woodbu and Wadsworth (1974). The black and white illustrations of leaves, flowe and fruit for each species are taken from these two publications.

In the matrix, the size ranges used are:

Height	**Crown Spread**
Short — less than 30 ft (9 m)	Narrow — less than 25 ft (7.5
Medium — 30 to 60 ft (9-18 m)	Medium — 25 to 50 ft (7.5-15
Tall — more than 60 ft (18 m)	Wide — more than 50 ft (15 m

Representative crown forms are illustrated on page 25 to 27. The form mos typical of each species is indicated; however, individual specimens may va depending on growth conditions and possible injuries to the crown. *Deciduous* means the species loses all of its leaves for at least a short tim during the year, usually during the dry season.

In the descriptions, common names are given in the top right corner, fir for Puerto Rico, then for the Virgin Islands or in English. If either one missing, there is no generally accepted common name. The favorabl points about each species are given in the headline and under **Uses a Features**. Problems that may be encountered are grouped under **Limitations**. The favorable points for each species should be balance against the limitations in determining whether the species is appropriate f your situation.

A statement that the roots are not troublesome or do not damag pavement or buildings means that this is true of the species in gener Individual trees, especially on very shallow soil or when they get very larg may still develop surface roots or a large trunk. Species known to ha troublesome roots are specifically mentioned.

Under **Rate of growth**, *rapid* means the tree should reach its mature size 5 to 10 years, *moderate* in about 15 years, and *slow* not for 20 years or re. Trees growing under exceptionally favorable conditions may develop ter, and trees growing under unfavorable conditions may develop re slowly.

he sizes under **Mature height** and **Crown diameter** are representative nature trees in Puerto Rico. Again, these may vary somewhat depending growing conditions.

nder **Remarks**, the place of origin and the usual method of propagation given for each species, along with special notes about use or care. Also ntioned briefly are some closely related species that are less widely used hat have undesirable characteristics.

					Tolerance				Uses	
Scientific and common name	Height	Crown Spread	Crown Form	Deciduous	Poor soil	Dry areas	Wet soil	Salt spray	Screening	Shade
Albizia lebbek (p. 34) Acacia amarilla Tibet	Medium	Medium	Round	X	X	X				X
Araucaria heterophylla (p. 35) Araucaria Norfolk-Island-pine	Tall	Narrow	Conical					Some		
Bauhinia monandra (p. 36) Mariposa Butterfly Bauhinia	Short	Narrow	Round	X	X	X			X	
Bucida buceras (p. 37) Ucar Gregre	Medium to tall	Medium	Oval		X	X	X	X		X
Bursera simaruba (p. 38) Almácigo Turpentine-tree	Medium	Medium	Oval	X	X	X		X		X
Callistemon citrinus (p. 39) Bottlebrush	Short	Narrow	Oval to round		X			Some	X	
Calophyllum calaba (p. 40) María Santa-maría	Medium to tall	Narrow	Oval to columnar		X		X	X	X	X
Cassia javanica (p. 41) Casia rosada Pink cassia	Medium	Medium	Umbrella	X						X
Casuarina equisetifolia (p. 42) Casuarina Australian beefwood	Tall	Medium	Columnar		X		X	X	X	
Ceiba pentandra (p. 43) Ceiba Silk-cotton-tree	Tall	Wide	Flat-topped	X	X	X				
Chrysophyllum cainito (p. 44) Caimito Star-apple	Medium	Medium	Round to oval			X				X
Clusia rosea (p. 45) Cupey Wild-mammee	Medium	Wide	Banyan		X		X	X	X	X
Cnidoscolus aconitifolius (p. 46) Papayuelo	Short	Narrow	Half round		X	X				X

ntific and common name	Height	Crown Spread	Crown Form	Deciduous	Tolerance Poor soil	Dry areas	Wet soil	Salt spray	Uses Screening	Shade	Showy Flowers
coloba uvifera (p. 47) a de playa a grape	Short	Narrow	Variable		X		X	X	X		
s nucifera (p. 48) lma de coco conut	Medium	Medium	Palm				X	X			
carpus erecta var. *sericea* (p. 49) ngle botón ver buttonwood	Short	Narrow	Prune to shape		X		X	X	X		
a alba (p. 50) reza blanca ite manjack	Short	Narrow	Round		X	X			X		X
a sebestena (p. 51) mitel colorado iger-tree	Short	Narrow	Round to oval		X	X		X			X
centia cujete (p. 52) üero abash-tree	Short	Narrow	Round	X	X	X					
ix regia (p. 53) mboyán mboyant-tree	Medium	Medium	Umbrella	X	X	X				X	X
nia malaccensis (p. 54) nzana malaya lay-apple	Medium	Narrow	Columnar to oval				X		X		X
benjamina (p. 55) rel de Benjamina jamin Fig	Medium	Wide	Banyan		X		X			X	
nekbuda (p. 56) can cloth-bark tree	Medium	Wide	Banyan	X	X		X	Some		X	
cum officinale (p. 57) yacán mmon lignum-vitae	Short	Narrow	Round		X	X			X	X	X
ma ulmifolia (p. 58) cima ocalalu	Medium	Medium	Half-round		X	X			X	X	
stroemia speciosa (p. 59) na de las flores en-of-flowers	Medium	Medium	Round						X	X	X

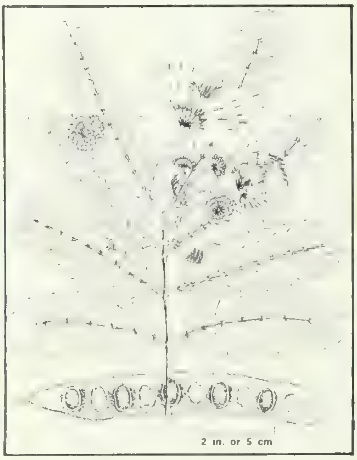
					Tolerance				Uses	
Scientific and common name	Height	Crown Spread	Crown Form	Deciduous	Poor soil	Dry areas	Wet soil	Salt spray	Screening	Shade
Mammea americana (p. 60) Mamey Mammee-apple	Medium	Narrow	Columnar to oval		X				X	
Mangifera indica (p. 61) Mango	Medium to tall	Medium	Round		X	X	X		X	X
Manilkara zapota (p. 62) Nispero Sapodilla	Medium	Narrow	Conical to oval			X			X	
Montezuma speciosissima (p.63) Maga	Medium	Narrow	Irregular to oval				X		X	X
Muntingia calabura (p. 64) Capulín	Short	Medium	Umbrella			X				X
Parkinsonia aculeata (p. 65) Palo de rayo Jerusalem-thorn	Short	Narrow	Round		X	X		X	X	
Peltophorum inerme (p. 66) Flamboyán amarillo Yellow flamboyant	Medium to tall	Medium	Round	X		X	X			X
Pithecellobium arboreum (p. 67) Cojoba	Medium	Narrow	Columnar	X						X
Plumeria rubra (p. 68) Frangipani	Short	Narrow	Irregular to flattened round	X	X	X		Some	X	
Pterocarpus indicus (p. 69) Pterocarpus India padauk	Tall	Medium	Round to weeping				X			X
Roystonea borinquena (p. 70) Palma real Puerto Rico royalpalm	Medium to tall	Medium	Palm		X		X			
Salix babylonica (p. 71) Sauce llorón Weeping willow	Short	Narrow	Weeping				X		X	
Sterculia apetala (p. 72) Anacagüita Panama-tree	Tall	Medium	Round to flat-topped			X				X

entific and common name	Height	Crown Spread	Crown Form	Deciduous	Tolerance				Uses		
					Poor soil	Dry areas	Wet soil	Salt spray	Screening	Shade	Showy Flowers
tenia macrophylla (p. 73) aoba hondureña oadleaf mahogany	Tall	Medium	Oval	X			X			X	
tenia mahagoni (p. 74) aoba dominicana est Indies mahogany	Medium	Medium	Round	X	X	X		Some	X	X	
buia heterophylla (p. 75) ble blanco hite-cedar	Medium	Narrow	Columnar to oval	X	X	X			X		X
rindus indica (p. 76) marindo marind	Medium	Medium	Round		X	X			X	X	
ma stans (p. 77) ble amarillo ger-thomas	Short	Narrow	Oval to round	X	X	X			X		X
nalia catappa (p. 78) nendra ian-almond	Medium	Medium	Broadly columnar		X		X	X	X	X	
besia populnea (p. 79) ajagüilla heita	Short	Narrow	Round		X		X	X	X		X

Albizia lebbek (L.) Benth.
Family: Leguminosae

Quick shade for difficult sites.

Uses: Shade and ornament along roads, in pastures, and in garden
Features: Grows rapidly in dry areas and on poor soils. Provides mediu shade except during the dry season when the leaves fall. Fragrant, yellowish-white powder-puff flowers are produced f about 4 weeks. Clusters of straw-colored pods remain on th tree almost all year and are especially conspicuous rattling the wind while the tree is leafless.
Limitations: Tends to have surface roots, especially in shallow soils, s should not be planted close to buildings or pavement. May see into gardens and pastures. Often has termite nests and tunne on its branches. A fungal disease sometimes attacks the roo and eventually kills the tree.
Description: Leaves doubly compound with numerous small, pale-gree leaflets. Flowers in rounded clusters across the crown. Fruit flat, broad pod. Flowering from April to September.
Rate of growth: Rapid.
Mature height: 20 to 40 ft (6 to 12 m).
Crown diameter: 25 ft (7.5 m).
Remarks: Native to southeast Asia. Easily propagated by seeds or cuttings. A related species, _Albizia procera_ (Roxb.) Benth. (albizia, tall albizia), with smaller and more numerous leafle and narrower pods that are reddish-brown, is extremely susceptible to root fungus, and should not be planted.



aucaria heterophylla* (Salisb.) Franco **Araucaria**
mily: Araucariaceae **Norfolk-Island-pine**

mmetrical Christmas tree for lawn or yard.

ses: Single accent tree.

atures: Erect, conical, symmetrical conifer with horizontal branches in regular whorls of 4 to 7. Grows best in good, well-drained soil with adequate moisture, tolerates salt spray.

nitations: Trunk often has a curve at the base before growing straight up, and some trees are spiral rather than completely vertical. Older trees become less symmetrical as they lose some of their lower branches. Should not be planted close to buildings because some of the large roots are relatively shallow. A fungus frequently discolors older needles, and a disease sometimes causes bleeding of resin from the trunk.

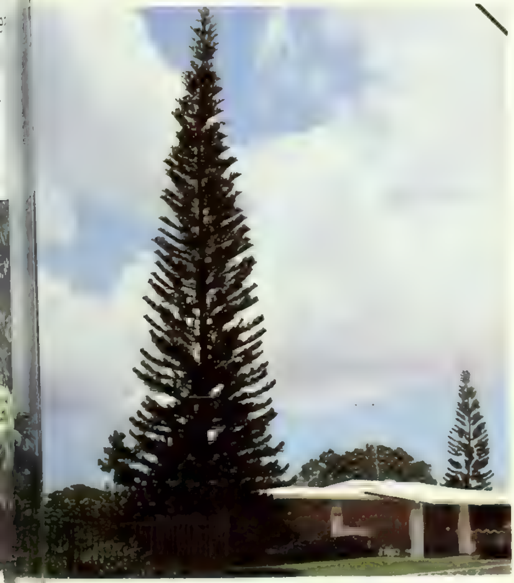
D scription: Leaves either needlelike or scaly on ropelike twigs arranged in a horizontal plane on the branches. Flowers inconspicuous. Fruit a rounded cone, rarely maturing in Puerto Rico.

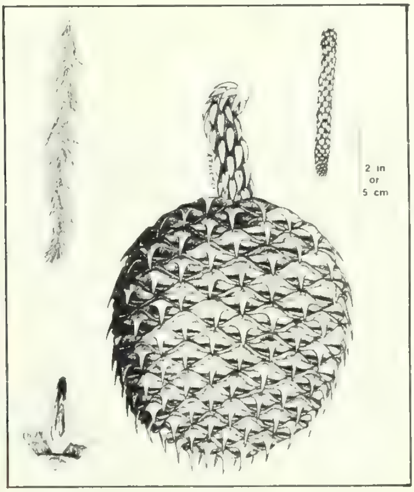
Rte of growth: Moderate.

Mture height: Probably 80 to 100 ft (24 to 31 m).

Cown diameter: 20 ft (6 m).

Rmarks: Native to Norfolk Island in the South Pacific. Propagated by seeds (which lose their viability quickly) or young tip cuttings. Several related species, which are not as symmetrical, are sometimes seen in Puerto Rico.





Bauhinia monandra Kurz
Family: Leguminosae

Marip
Butterfly bauh
Pink orchid

Flowering tree for confined areas.

Uses: In gardens, along roads and sidewalks, or wherever a sm flowering tree is needed.

Features: Covered with large pink, red-spotted, orchid-like flowers about 2 months. Grows in most soils but does best with g drainage. Roots and trunk do not cause problems with waterlines or pavement.

Limitations: Nothing serious.

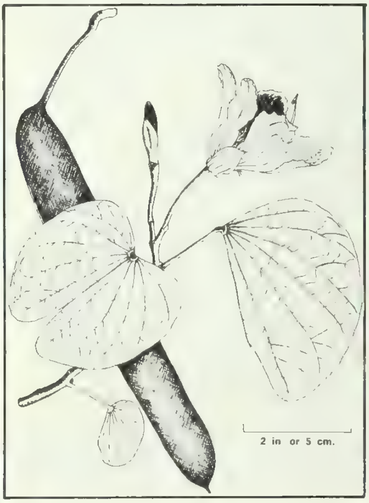
Description: Leaves light green, split about ⅓ of their length into 2 lo resembling a cow's hoof. Flowers in short terminal cluste Fruit a narrow, reddish-brown pod. Flowering and fruiting almost throughout the year, but with peak flowering betw May and September.

Rate of growth: Rapid. Tree lasts about 30 years.

Mature height: 10 to 30 ft (3 to 9 m).

Crown diameter: 15 ft (4.5 m).

Remarks: Native to southeast Asia. Propagated by seeds; needs car transplanting so roots are not disturbed. Can be pruned flowering, but only lightly because the flowers are produce the twigs from the previous year. *Bauhinia variegata* L. (pal orquídeas, poor-man's-orchid), with flowers varying from to purple, and *Bauhinia blakeana* S.T. Dunn. (Hong Kon orchidtree), with large clusters of fragrant deep crimson flowers, are also becoming popular in Puerto Rico.



***cida buceras* L.**
nily: Combretaceae

Ucar
Gregre
Oxhorn bucida

cellent shade tree for confined areas and adverse conditions.

es: Shade, windbreaks, and ornament for gardens, roadsides, and areas near the shore.

tures: Grows well in sandy soils, calcareous soils, or shallow volcanic soils, and resists wind, salt spray, and drought. Evergreen except in very dry areas, therefore provides shade and protection throughout the year. Deep root system does not damage buildings or pavement. Said to be hurricane resistant.

itations: Fruits may cause tannin stains on parked cars. One variety of this tree, susceptible to mites that cause continuous leaf fall, should not be propagated.

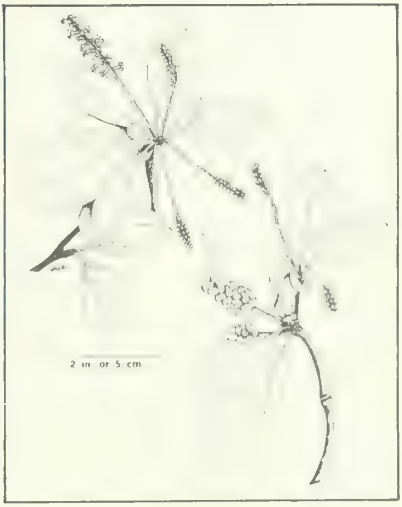
scription: Leaves yellowish-green, clustered at ends of short twigs along the branches. Flowers inconspicuous. Fruit brownish, clustered in long spikes with some fruits deformed into horn-like galls. Flowering and fruiting irregularly throughout the year.

e of growth: Moderate, but slow if root system is restricted.

ure height: 30 to 60 ft (9-18 m) or more.

wn diameter: 40 ft (12 m).

narks: Native to Puerto Rico and the Virgin Islands. Propagated by cuttings or air layers from plants selected for small leaves and symmetrical form. Grows best in full sunlight and with good drainage. Responds well to pruning and fertilization.



Bursera simaruba (L.) Sarg.
Family: Burseraceae

Almácigo
Turpentine-tree

Living fence post with smooth, flaking, reddish-brown bark.

Uses: Open shade along streets or beach, but loses its leaves in the dry season. Single accented or background tree in gardens or parks.

Features: Adapted to limestone soils, grows best in dry or well-drained areas. Tolerant of drought, wind, and salt spray. Branches up to 4 inches (10 cm) in diameter will root and grow when stuck in the ground.

Limitations: Nothing serious.

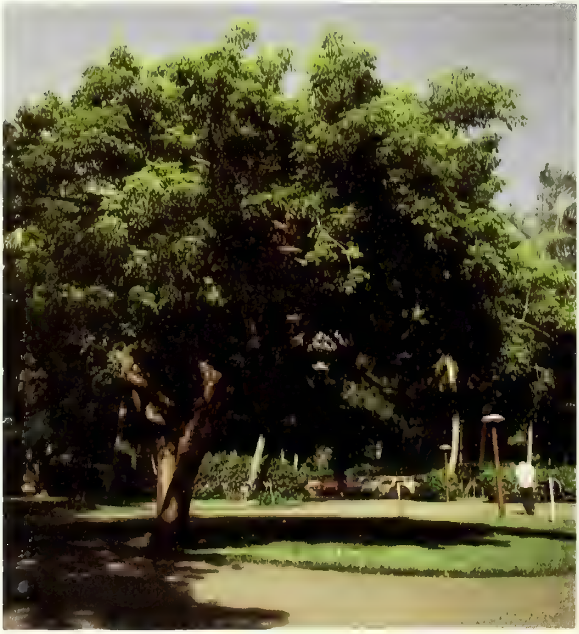
Description: Leaves composed of 3 to 7 leaflets with aromatic odor when crushed. Flowers yellowish-green, inconspicuous. Fruit reddish and diamond-shaped. Flowering and fruiting usually in spring before or with the new leaves. Crown composed of large crooked, spreading branches arising from a stout trunk.

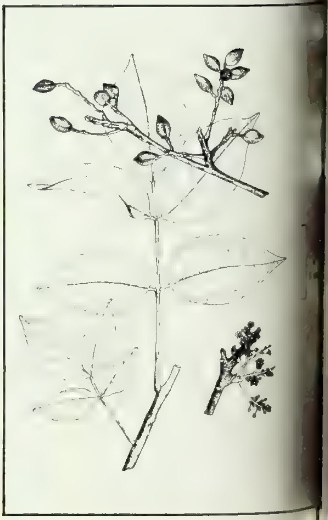
Rate of growth: Moderate.

Mature height: 20 to 40 ft (6 to 12 m).

Crown diameter: 25 ft (7.5 m).

Remarks: Native to Puerto Rico and the Virgin Islands. Can also be propagated by seeds.





temon citrinus (Curtis) Skeels **Bottlebrush**
y: Myrtaceae

tree with brilliant red flowers; good for confined areas.

Ornament in patios, along sidewalks and median strips, and in parking lots and other areas where space is limited.

tres: Grows under widely varying conditions. Tolerates poor soil, drought, and some salt spray.

tions: Nothing serious.

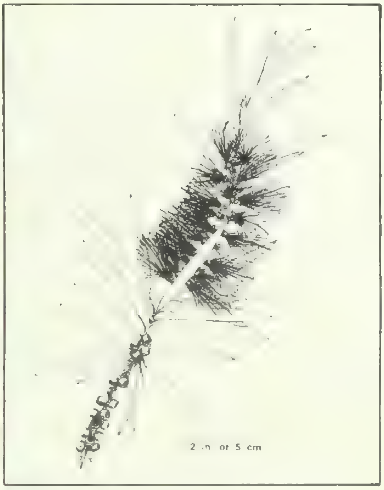
iption: Leaves narrow and pointed, spread all around twig, with a lemon odor when crushed. Flowers in bottle-brush-like masses near the ends of slender, drooping twigs. Fruit a hard, rounded, brown woody capsule, surrounding twigs in clusters and persisting for several years. Flowering and fruiting irregularly throughout the year. May be shrubby with several stems.

of growth: Moderate.

ue height: 20 ft (6 m).

diameter: 15 ft (4.5 m).

rks: Native to Australia. Propagated by seeds.



Calophyllum calaba L.
Family: Guttiferae

Maria
Santa-maria
False-mamey

Beautiful, dense, dark-green shade for street borders and poor soils.

Uses: Shade, ornament, and in dense hedges as a windbreak or to protect from salt spray near the ocean.

Features: Grows well in almost all soils, especially adapted to degraded sites, and resistant to salt spray. The dark, shiny green crown can be shaped into a hedge or other form, and the tree can be used in confined areas if controlled by pruning.

Limitations: Grows slowly, especially on poor sites.

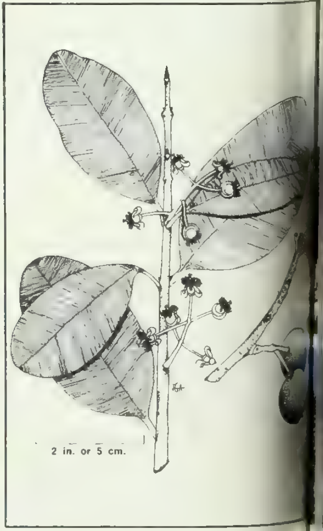
Description: Leaves stiff and dark green. Flowers numerous, small, white, fragrant, in clusters. Fruit light brown, hard and dry. Flowering mostly in spring and summer, with fruits maturing mainly in fall.

Rate of growth: Slow.

Mature height: 40 to 65 ft (12-20 m).

Crown diameter: 20 ft (6 m).

Remarks: Native to Puerto Rico and the Virgin Islands. Easily propagated by seeds, but the young seedlings must be transplanted with a ball of earth for good survival. If the tree is to be shaped by pruning, this should be started while it is still young, especially if used to line sidewalks or roadsides. This species is long-lived and develops a large trunk, which may eventually cause problems to sidewalks.



***ia javanica* L.** **Casia rosada**

ly: Leguminosae **Pink cassia**

tacular masses of fragrant, long-lasting pink flowers.

: Single accented or background tree in gardens or parks where litter will not be a problem.

res: Flowers completely cover the outer ends of the spreading branches for 2 to 3 months. Grows and flowers best in good, well-drained soil with adequate moisture.

ations: Loses its leaves during the dry season, and is not particularly attractive then because it has many long hanging pods and dead branches. The falling leaves, flower parts, and pods (which have a bad odor when green) make it a poor choice for streets or parking lots. Also, it should not be planted close to buildings because of the spreading crown, and it has a shallow root system so may be blown over by hurricane-force winds.

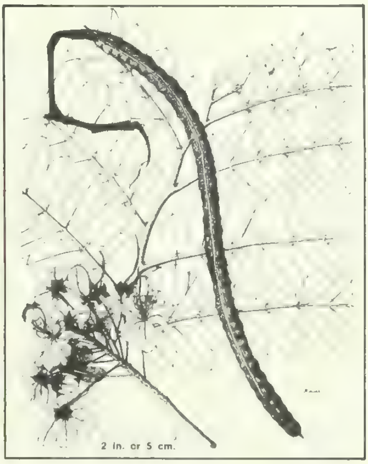
ciption: Leaves composed of about 16 to 20 pairs of leaflets, the new ones appearing just before the flowers. Flowers rose-scented, numerous in lateral clusters. Fruit a slender cylindrical, dark-brown pod 16 to 20 inches (21 to 51 cm) long. Flowering mainly from May to July.

e f growth: Rapid. Tree seldom lasts more than 30 years.

u height: 40 ft (12 m).

w diameter: 30 ft (9 m).

ks: Native to India and southeast Asia. Propagated by seeds. Will flower within about 5 years of planting, with maximum flowering after a long dry season. Needs early pruning because it tends to fork near ground, and dead branches should be pruned out of the top periodically for best appearance.



***Casuarina equisetifolia* L.** **Casuar**
Family: Casuarinaceae **Australian beefw**

Outstanding for beaches and windbreaks.

Uses: Windbreaks, screens, and hedges in coastal areas, and f binding and building soil on beach sands.

Features: Grows on acid and alkaline soils, muck, calcareous rocky so and sand dunes. Withstands drought and heavy salt blas

Limitations: Spreading superficial root system may cause trouble if th is not plenty of room, and very tall trees may be blown over hurricane-force winds. Little other vegetation will grow un the crown because the fallen "needles" decay slowly. A disease that causes stem cankers, dieback, and sometim death of large old trees has been reported in several area Puerto Rico, so this species should not be planted for permanent use near buildings. It should be used only for bea plantings, windbreaks, and sheared hedges or screens.

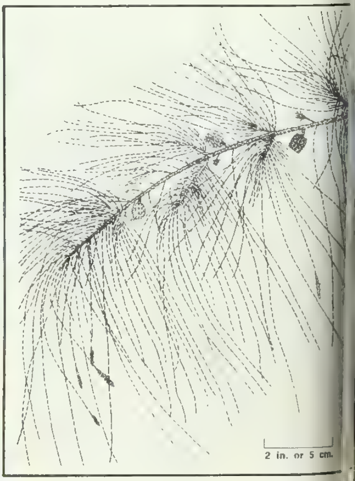
Description: Needle-like leaves are actually green modified twigs with scale-like true leaves at the joints. Flowers inconspicuous. F a light-brown, warty, conelike ball. Flowering and fruiting throughout the year.

Rate of growth: Very rapid.

Mature height: Up to 100 ft (31 m).

Crown diameter: 25 ft (7.5 m).

Remarks: Native to Australia and tropical Asia. Propagated by seed cuttings, does not produce root sprouts. Has thin open cr but can be sheared to control height and form a dense hedg screen, or can be planted in a belt several trees thick to for windbreak.



iba *pentandra* (L.) Gaertn. **Ceiba**
nily: Bombacaceae **Silk-cotton-tree**

nt tree with large buttresses.

es: Centerpiece for park or plaza, or along rural highway.

tures: Massive, gray, smooth trunk up to 8 ft (2.5 m) in diameter above narrow buttresses that may be up to 6 ft (1.8 m) high and extend to 10 ft (3 m) out over the wide-spreading, shallow roots. Broad, flat-topped crown of spreading horizontal branches. Grows on poor soils in both moist and dry areas.

itations: Large trunk, buttresses, and surface roots make it difficult to grow anything else under it.

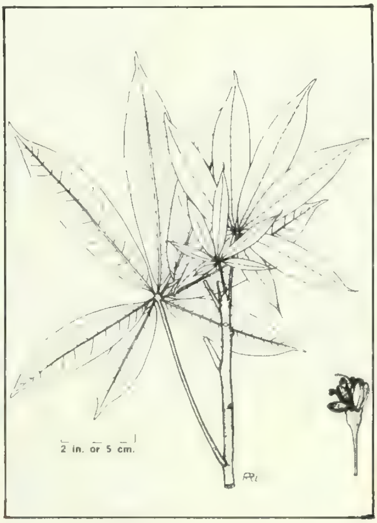
cription: Leaves composed of 5 to 8 palmately arranged leaflets. Flowers white to pinkish, in clusters near the ends of the twigs. Fruit a pod-like hanging capsule containing gray floss (the kapok of commerce) with embedded seeds. Flowering from December to February, not every year and often while the tree is leafless, and with fruits maturing about 2 months later.

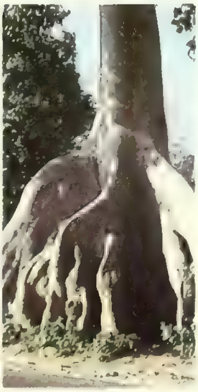
a of growth: Moderate. May take 50 years to reach mature size and form.

ure height: 80 ft (25 m) or more.

wn diameter: 80 ft (25 m).

arks: Native to Puerto Rico and the Virgin Islands. Propagated by cuttings or by seedlings with the tops cut back. Young trees have spines on the bark, and have open, irregular crowns.

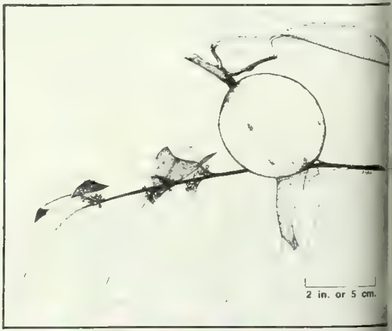


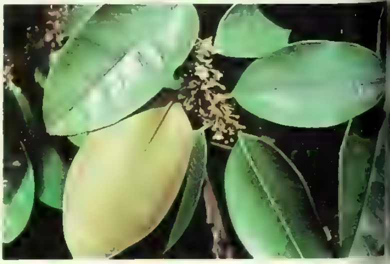


***Chrysophyllum cainito* L.** **Caim**
Family: Sapotaceae **Star-ap**

Evergreen shade tree with attractive reddish-brown leaves and edible fru

Uses: Shade, ornament, and fruit in yards and gardens.
Features: Dense, spreading crown with slightly drooping branches. Grows best on moist, well-drained soil. Fruit can be eaten fres or used in salads, and production starts in about 5 years.
Limitations: Nothing serious.
Description: Leaves dark green and slightly shiny above; silky, reddish-golden-brown below and on petioles and young twig Flowers tiny, purplish-white, clustered at base of leaves. Fr greenish to purplish when ripe, with a thick, leathery rind containing gummy latex; the white jellylike flesh and brow seeds make a star-shaped pattern when cut. Flowering in summer and fall and fruiting from late fall to summer. Repute does not fruit in the Virgin Islands.
Rate of growth: Slow.
Mature height: 20 to 40 ft (6 to 12 m).
Crown diameter: 25 ft (7.5 m).
Remarks: Native to Greater Antilles, possibly including Puerto Rico. Propagated by seeds, which should be selected from trees w good fruit. Tree contains milky sap.





usia rosea Jacq. **Cupey**

mily: Guttiferae **Wild-mammee**

oad, spreading evergreen with stiff leaves resistant to salt spray.

es: Along seacoast, and in parks or large gardens where there is room for a wide-spreading tropical tree.

atures: Grows on most soils and tolerates salt spray and drought. Forms prop roots at base and aerial roots from branches, so may completely take over area where it is growing. Can be pruned to shape.

nitations: Falling leaves and fruits may cause a litter problem.

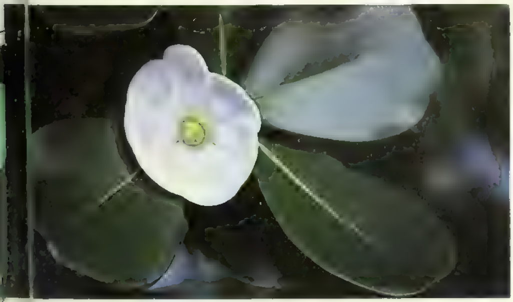
scription: Leaves thick and leathery. Flowers pink to light rose, terminal at ends of twigs but not enough blooming at one time to create a display. Fruit considered to be poisonous, ball-like and fleshy, yellow-green turning to brown and splitting at maturity to reveal several yellow seeds in orange-red pulp. Flowering and fruiting throughout the year.

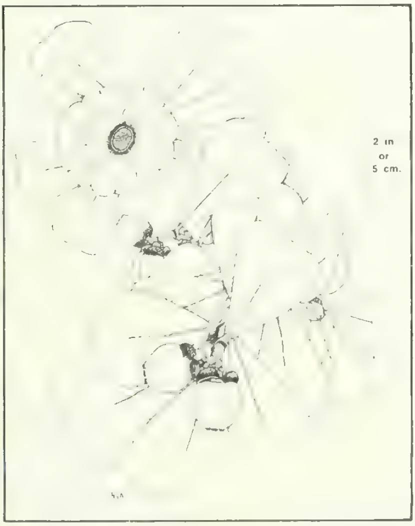
te of growth: Moderate.

ture height: Up to 60 ft (18 m).

own diameter: 75 ft (23 m).

marks: Native to Puerto Rico and the Virgin Islands. Propagated by seeds and cuttings. Seeds may stick to other plants and germinate as epiphytes. Messages have been written on the leaves. Dried fruits are used in floral arrangements. Tree contains a yellow, resinous latex.

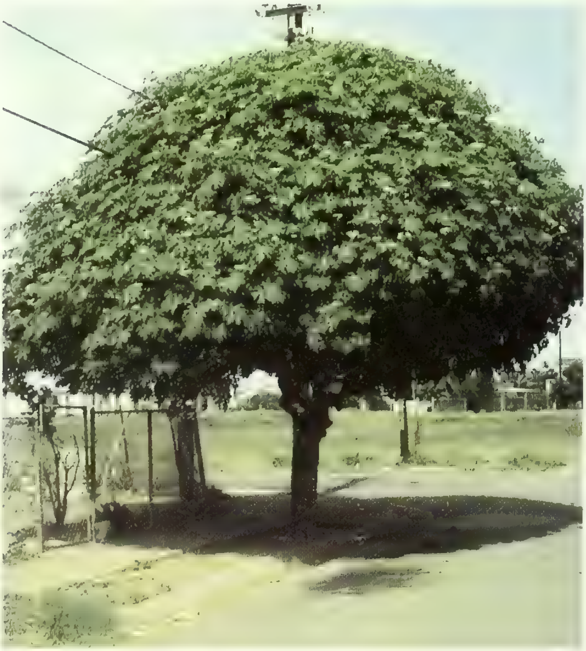


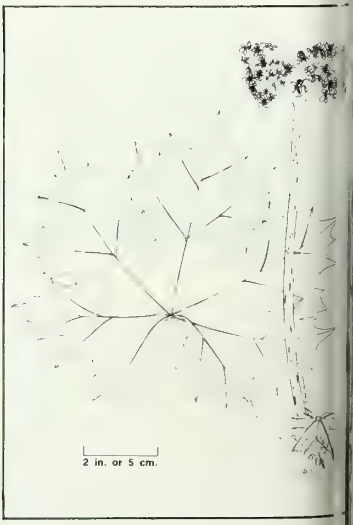


Cnidoscolus aconitifolius (Mill.) I.M. Johnst. **Papayue**
Family: Euphorbiaceae

Small tree for quick shade and ornament in dry areas.

Uses: Shade and ornament in gardens and patios.
Features: Compact, dense, half-round crown on short, stout trunk; numerous small, white flowers. Grows well on any soil in c areas.
Limitations: Sometimes attacked by insect that causes leaves to turn yellow and fall off. Not well suited for planting along roads because branches are easily broken.
Description: Leaves palmately lobed, dull dark green with many light-green veins. Flowers fragrant in clusters across the crow Flowering throughout the year but not producing fruit in Puer Rico.
Rate of growth: Very rapid. Tree lasts only about 10 years.
Mature height: 20 ft (6 m).
Crown diameter: 20 ft (6 m).
Remarks: Native to Mexico. Propagated by cuttings (and seeds). Sto green twigs have scattered stinging hairs and yield abunda white latex when cut.





occoloba uvifera (L.) L. **Uva de playa**
amily: Polygonaceae **Sea grape**

xcellent small tree, hedge, or ground cover for beach areas; edible fruit.

ses: Tree or hedge where salt spray is a problem; highway median strips; in sheltered locations as an unusual tree with wide-spreading branches.

eatures: Grows with little or no care on sandy and rocky seashores, withstands heavy salt blast and wind and grows well in both full sun and partial shade. Can be pruned to form a windbreak or privacy screen. Also grows well on good soils and under sheltered conditions.

mitations: Leaves sometimes attacked by insects, causing bad appearance and leaf fall.

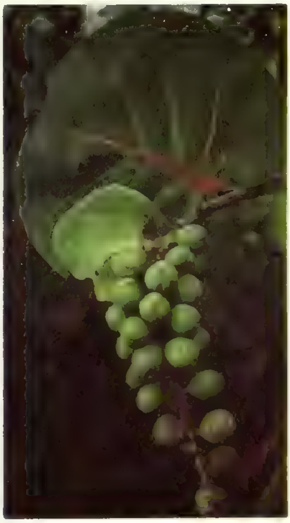
escription: Leaves thick and leathery, bluish-green with red veins, young and very old leaves often reddish. Flowers fragrant and very small in long, narrow clusters. Fruit grapelike in drooping clusters, purple when mature. Flowering and fruiting throughout the year.

ate of growth: Moderate.

ature height: Highly variable, up to 25 ft (7.5 m) under optimum conditions.

rown diameter: 20 ft (6 m).

emarks: Native to Puerto Rico and the Virgin Islands. Propagated by seeds and cuttings. Male and female flowers are on different trees, so a female cutting should be used if fruit is desired. Fruit is used in salads and makes good jelly.



***Cocos nucifera* L.** **Palma de co**

Family: Palmae **Cocor**

Graceful palm that is one of man's most useful plants.

Uses: Beach areas, rural highways, for tropical effect in gardens ar parks, and possibly along streets if the leaves and nuts are ke trimmed. Most effective when planted in groups.

Features: Grows on most soils but does best on sandy soil with goo drainage, withstands salt spray and strong winds and ever inundation by salt water for short periods. Also grows inla and in dry areas if irrigated. Can often withstand hurricane although it loses its leaves.

Limitations: Mature leaves and nuts must be kept trimmed for safety passersby, and trimming can be a problem when the palm tall. A scale insect damages the leaves and is difficult to contr after the palm is tall. Lethal yellowing, for which no cure is y known, has decimated palms in Florida and Jamaica. It has no yet reached Puerto Rico, but it is advisable to plant the disease-resistant Malayan dwarf variety, which also is shor and has smaller nuts.

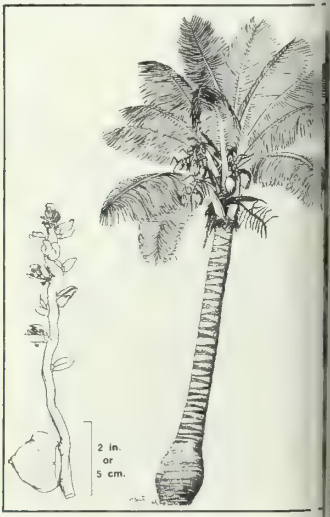
Description: Usually slender, leaning trunk with enlarged base, toppe with a crown of feathery leaves at the base of which are lon ivory-colored inflorescences and the familiar coconuts. Flowering and fruiting throughout the year.

Rate of growth: Moderate.

Mature height: 30 to 60 ft (9 to 18 m) or more.

Crown diameter: 25 ft (7.5 m).

Remarks: Probably native to the Indo-Malayan region. Propagated b planting the nuts.



onocarpus erecta L. var. sericea Forst. ex DC. **Mangle botón**
amily: Combretaceae **Silver buttonwood**

mall, silver-leaved, salt-resistant tree for confined areas.

ses: Beach areas; patios, sidewalks, and other areas where space is limited; also as a hedge or screen if pruned.

eatures: Grows in sand, on poor soils or those high in calcium, and on brackish swampy ground, withstands heavy salt blast but can also be grown inland. Considered a shore-builder and grows best in full sun.

imitations: Nothing serious.

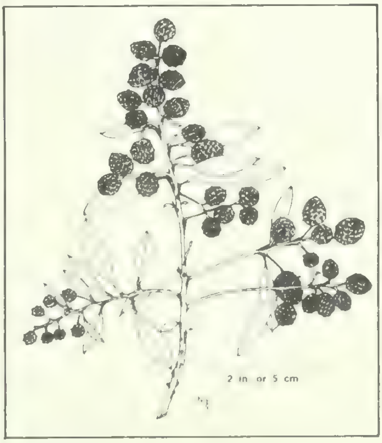
escription: Leaves leathery and slightly fleshy, covered with pale, silky down that causes the silvery appearance of this variety. (The typical species has hairless, yellow-green leaves and grows on the landward side of tidal mangrove swamp forests throughout Puerto Rico and the Virgin Islands). Flowers minute in small clustered greenish balls. Fruit purplish-brown, small, rounded, and conelike. Flowering and fruiting throughout the year.

ate of growth: Moderate.

ature height: Varies from small shrub to 20 ft (6 m).

rown diameter: 10 ft (3 m).

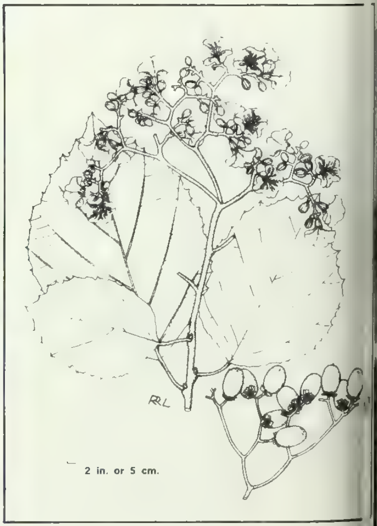
emarks: The typical species is native to Puerto Rico and the Virgin Islands, and the silver-leaved variety was developed in Florida. Propagated by hardwood cuttings or air layers. For best appearance should be pruned about 3 times a year to a height of about 15 ft (4.5 m) and a crown diameter of about 10 ft (3 m). Should be fertilized after pruning.



Cordia alba (Jacq.) Roem. & Schult. Cereza blan
Family: Boraginaceae White manja

Small, flowering tree for dry areas.

Uses: Ornament and some shade around houses, also for living fences if planted close together.
Features: Grows in dry, rocky areas; has showy whitish to pale-yellow flowers; fruits are good for wildlife.
Limitations: Fleshy fruits may be messy when they fall.
Description: Leaves and twigs hairy. Flowers in erect terminal clusters u to 10 inches (25 cm) wide. Fruit whitish and containing a whitis pulp. Flowering and fruiting throughout the year.
Rate of growth: Moderate.
Mature height: 20 ft (6 m).
Crown diameter: 20 ft (6 m).
Remarks: Native to the Virgin Islands and probably also Puerto Rico. Propagated by seeds. A related species, *Cordia obliqua* Will (cereza blanca, manjack), with leaves only slightly toothed ar fruit pinkish, has been introduced and is more commonly use as an ornamental in the dry areas of northeastern Puerto Ric



***ordia sebestena* L.** **Vomitel colorado**

amily: Boraginaceae **Geiger-tree**

mall tree with showy flowers for dry areas and near the shore.

ses: Gardens and patios; along streets and in parking lots if the lower branches are pruned; seashore planting.

eatures: Dense, compact, rounded crown and clusters of orange or red flowers. Grows on brackish and sandy or alkaline soils as well as on coral rock and marl, but does best in dry areas with good drainage. Withstands wind and salt spray. Produces flowers when still small and, after long dry spells, may produce a flush of bloom lasting up to a month. Requires little care once established.

mitations: May lose its leaves during extremely dry periods.

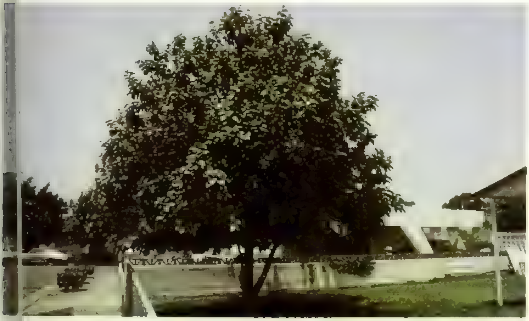
escription: Leaves deep green, coarse, and somewhat hairy. Flowers trumpet-shaped in terminal clusters. Fruit egg-shaped and whitish. Flowering and fruiting throughout the year.

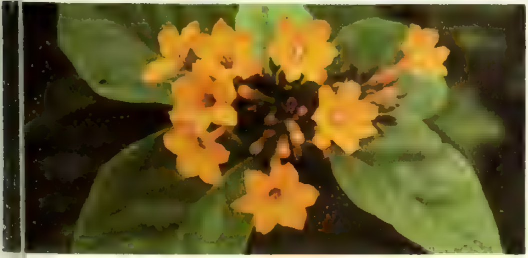
ate of growth: Moderate.

ature height: 20 ft (6 m).

rown diameter: 15 ft (4.5 m).

emarks: Native to the Caribbean area including Central America and northern South America, but not to Puerto Rico. A similar species, *Cordia rickseckeri* Millsp. (San Bartolomé, manjack), is native to Puerto Rico and the Virgin Islands. Propagated by seeds, cuttings, and air layering.

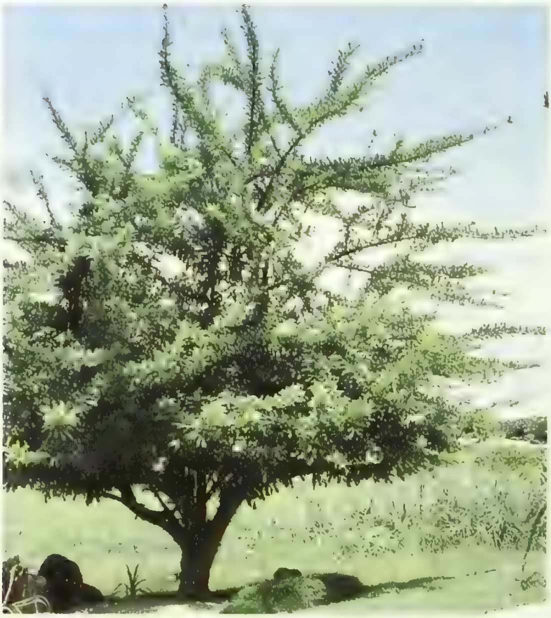


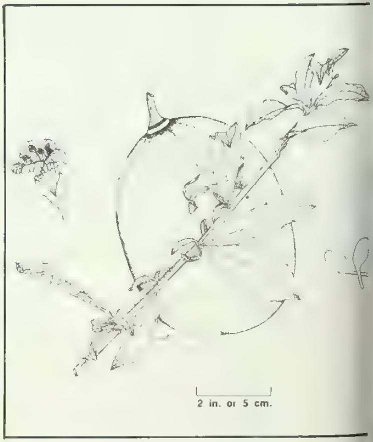


Crescentia cujete L. **Higüe**
Family: Bignoniaceae **Calabash-tr**

Small spreading tree with large gourd fruit.

Uses: For decorative effect in yard.
Features: Grows in dry areas and on poor soils but does best in mois areas. Open foliage makes it good for growing hanging orchi and other epiphytes. Roots will not damage sidewalks.
Limitations: Flowers have bad odor, and pulp of fruit is poisonous. Som times attacked by a leaf-webbing caterpillar.
Description: Leaves mostly in clusters of 3 to 5 towards the ends of t stout twigs. Flowers bell-shaped, light green streaked with purple. Fruit green to brown with hard shell that does not sp open. Flowers and fruit borne singly directly on trunk and branches. Flowering and fruiting throughout the year.
Rate of growth: Moderate.
Mature height: 20 ft (6 m).
Crown diameter: 20 ft (6 m).
Remarks: Native to Puerto Rico and the Virgin Islands. Propagated b seeds and cuttings. String tied around the fruits while they ar maturing can force them to grow into various shapes.





***onix regia* (Bojer) Raf.** **Flamboyán**
mily: Leguminosae **Flamboyant-tree**
Royal poinciana

liant masses of long-lasting, orange-red flowers on spreading crown.

es: Ornament and shade in parks and gardens where there is room for such a spreading tree, often planted along highways.

tures: One of the world's most beautiful flowering trees. Grows on most soils, does best with full sunlight and a dry period to induce maximum flowering.

itations: Trunk develops buttresses, and shallow root system may damage sidewalks, walls, or buildings. Usually has termite tunnels and nests on trunk and branches, and wounded trees are susceptible to termite attack, which makes them more liable to wind damage. Sometimes attacked by a root fungus that kills the tree. Also, occasionally defoliated by a caterpillar.

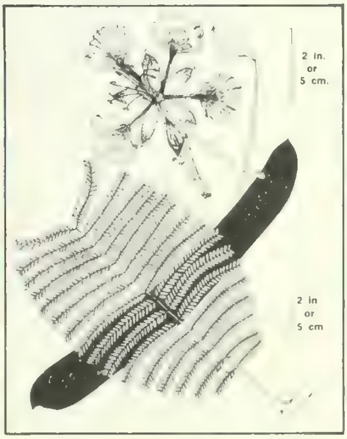
scription: Leaves doubly compound with many small, paired leaflets; leafless for about a month in the dry season until shortly before the flowers appear. Flowers in 6- to 10-inch (15-25 cm) clusters, lasting at least 2 months. Fruit a flat, black, woody pod. Flowering from May to August and with hanging pods most of the year.

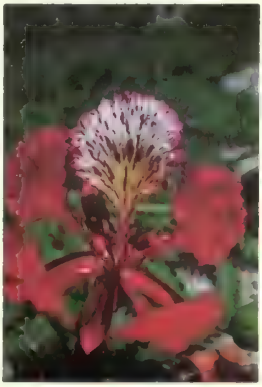
e of growth: Rapid.

ure height: 20 to 50 ft (6 to 15 m).

wn diameter: 50 ft (15 m).

narks: Native to Madagascar but widely planted throughout the tropics. Propagated by seeds. Dead branches should be pruned for best appearance, and trees along highways are often trimmed to arch over the road. A less common yellow-flowered variety exists.

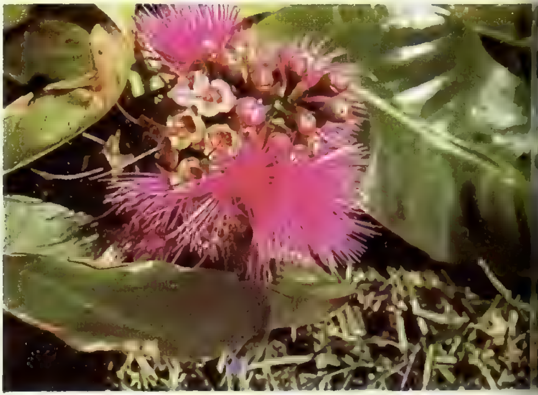


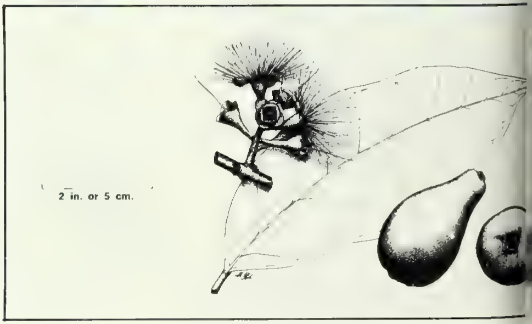


Eugenia malaccensis L. **Manzana mal**
Family: Myrtaceae **Malay-ap**

Columnar evergreen for ornament, screening, and shade.

Uses: Good for confined areas because crown is small and roots r troublesome.
Features: Grows on most soils but does best on good, moist soil. Crow dense, with purplish-red flowers and reddish fruits borne behind the leaves.
Limitations: Nothing serious.
Description: Leaves dark green and leathery. Flowers in clusters, composed of a mass of red stamens that carpet the grou when they fall. Fruit pear-shaped with thin, soft skin; edible with rather insipid flavor. Flowering and fruiting throughout t year.
Rate of growth: Moderate.
Mature height: 15 to 40 ft (4.5 to 12 m).
Crown diameter: 15 ft (4.5 m).
Remarks: Native to Malaysian area. Propagated by seeds.





us benjamina L. **Laurel de Benjamina**
nily: Moraceae **Benjamin fig**

nyan-type fig with small leaves and evergreen crown spreading more n twice as wide and tall.

s: Parks, school grounds, wide lawns, and similar areas where a dense, spreading shade tree is appropriate.

tures: Short trunk supporting many stout, wide-spreading, almost horizontal branches that curve nearly back toward the ground, with wirelike air roots. Air roots also run down the main trunk to form a mass 5 ft (1.5 m) or more across and sometimes extend across the ground. Does best in moist areas.

itations: Needs much room for the roots, and most other plants or grass will not grow under it because of the dense shade. Roots may interfere with walks and other structures, and will grow into sewer pipes and septic systems.

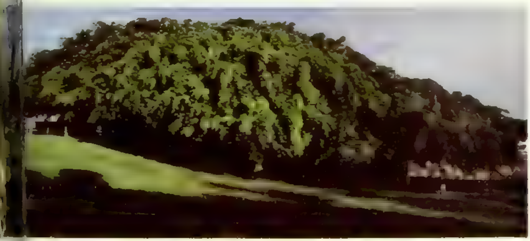
cription: Leaves dark green and shiny. Flowers are inside the fruits, which are dark red to purplish at maturity. Fruiting in spring and fall. Milky latex exudes from cut parts.

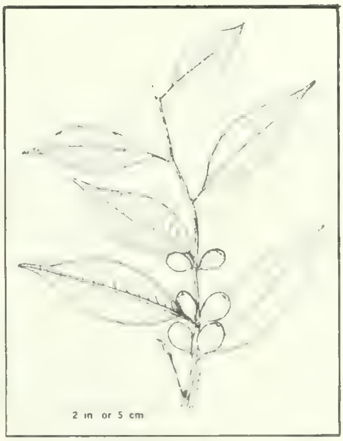
e of growth: Rapid to moderate.

ure height: 30 ft (9 m) or more.

wn diameter: 80 ft (24.5 m).

arks: Native to southeast Asia. Propagated by air layers. Spread of branches and roots can be controlled by pruning, to which it responds better than *Ficus nekbuda*.





Ficus nekbuda Warb. **African cloth-bark**

Family: Moraceae

Banyan-type fig with large leaves and dense crown wider than tall.

Uses: Shade and ornament along streets and highways where th is enough room.

Features: Trunk and surrounding air roots may form mass 5 ft (1.5 m more in diameter, forking at 5 to 10 ft (1.5 to 3 m) into sev stout, wide-spreading branches that often have air roots hanging from them. Grows in most soils if moisture is availa Tolerates some salt spray.

Limitations: Needs large space for trunk and roots. Loses its leaves April, and this plus the falling fruits in May and June may ca a litter problem. Sometimes attacked by mealy bugs. Roo may interfere with walks and structures, and will grow int sewer pipes and septic systems.

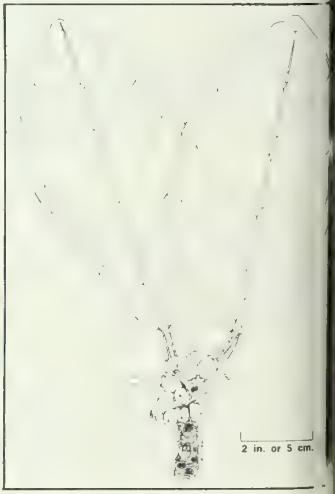
Description: Leaves crowded at ends of twigs, dark green, stiff, leath and much larger than those of *Ficus benjamina*. Flowers inside the yellow-green fruits, which are clustered near tw ends behind the leaves. Milky latex exudes from cut part

Rate of growth: Moderate.

Mature height: 40 ft (12 m).

Crown diameter: 60 ft (18 m).

Remarks: Native to tropical East Africa. Propagated by air layers. Size be controlled by pruning. A related tree, the "decora" cultiva *Ficus elastica* Roxb. ex Hornem (palo de goma, India-ru fig), with many parallel veins in the leaves and long, red term buds, has many of the same attributes but is not as wid suitable.



aiacum officinale L. — Guayacán
mily: Zygophyllaceae — Common lignumvitae

nse green foliage and blue flowers on a tree for confined areas.

es: Ornament and screening in limited spaces.

atures: Grows naturally on dry south coast of Puerto Rico, and does well in both dry and moist areas, but needs dry season for best flowering. Dense, rounded crown and evergreen habit make it good for screening or small windbreaks.

nitations: Nothing serious except for slow growth rate.

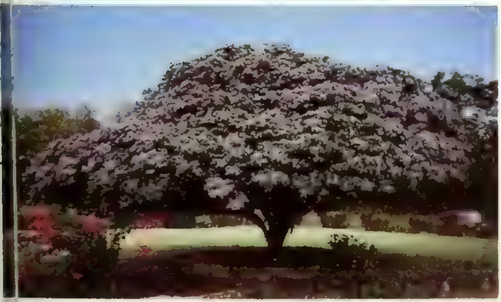
scription: Leaves composed of 2 to 3 pairs of dark-green leaflets. Flowers in showy clusters, slightly fragrant. Fruit orange-brown, flattened, and heart-shaped. Flowering and fruiting from spring to fall, often with 1 or 2 heavy blooming periods each lasting about 1 month.

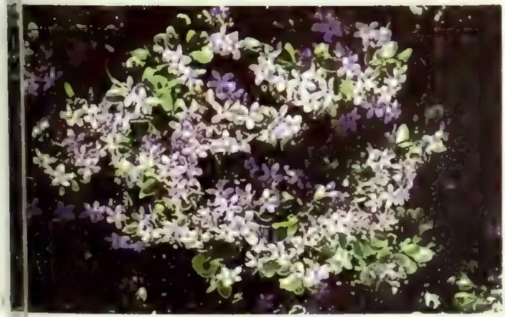
e of growth: Slow.

ture height: 15 to 30 ft (4.5 to 9 m).

wn diameter: 20 ft (6 m).

marks: Native to Puerto Rico and the Virgin Islands. Propagated by seeds, or by wildlings that require extreme care in transplanting. Because of slow growth rate, seedlings should be grown in nursery for several years before planting.

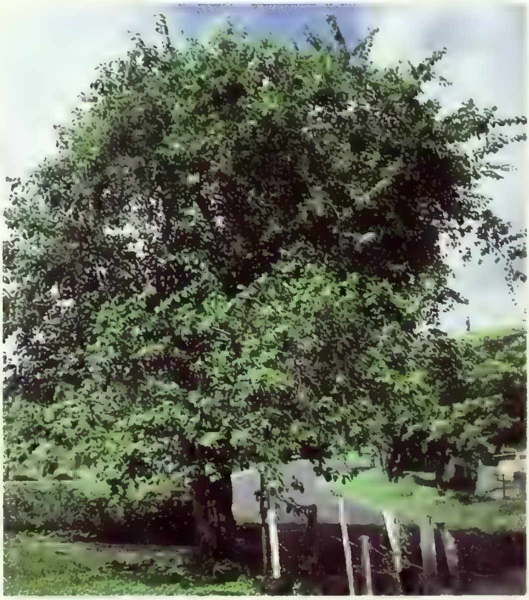


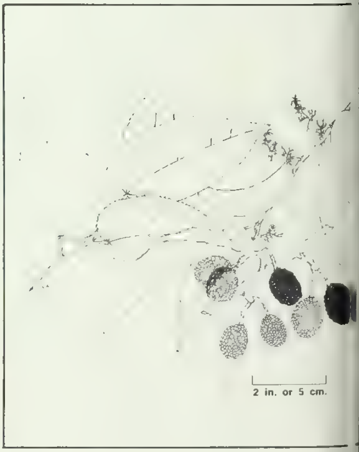


Guazuma ulmifolia Lam. **Guác**
Family: Sterculiaceae **Jacoca**

Fast-growing shade tree for dry areas.

Uses: Shade around houses, along streets, and in pastures.
Features: Hardy in both dry and moist areas, but grows best in full sunl where moisture is available in dry areas. Can be used in confined areas because roots are not troublesome. Has spreading, rounded crown of long, horizontal, wide-spread branches.
Limitations: Fruits may be a temporary litter problem in lawns.
Description: Leaves finely saw-toothed, hanging vertically at night, evergreen except where dry season is severe. Flowers inconspicuous in clusters at base of leaves. Fruit rounde black, hard, and warty. Flowering from March to October with fruit throughout the year.
Rate of growth: Moderate.
Mature height: 50 ft (15 m).
Crown diameter: 30 ft (9 m).
Remarks: Native to Puerto Rico and the Virgin Islands. Propagated seeds or wildlings. Good tree for dry areas because it gr slowly and develops a dense crown. In wet areas it becom straggly.





gerstroemia speciosa (L.) Pers. **Reina de las flores**
mily: Lythraceae **Queen-of-flowers**

lliant masses of long-lasting, purple or pink flowers.

es: Shade and ornament in parks, gardens, and along streets.

atures: Numerous showy flowers cover the crown for about 2 months. Grows in most soils but does best in moist, well-drained soil, although it withstands short periods of flooding. May be pruned to keep it small.

nitations: Loses some of its leaves during dry season (or all of them where drought is severe) and looks rather ragged, especially with the dry fruit capsules remaining on the tree.

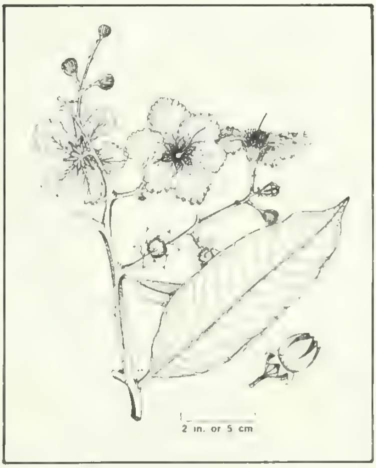
scription: Leaves appear to be in 2 rows on twigs. Flowers in large terminal clusters above the leaves, usually purple or lavender, but pink on some trees. Fruit rounded and gray-brown. Flowering from May through October and with fruits maturing from winter to summer.

te of growth: Moderate.

ture height: 20 to 50 ft (6 to 15 m).

wn diameter: 25 ft (7.5 m).

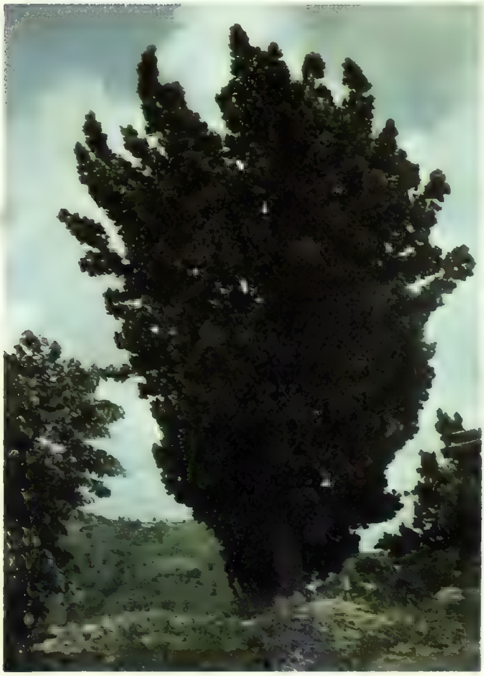
marks: Native to Far Eastern area. Propagated by seeds or cuttings. Seedlings should be pruned and staked to develop erect stem. They start flowering the year after planting. Fruit capsules can be pruned off after flowering to improve appearance and enhance flowering in the next year.

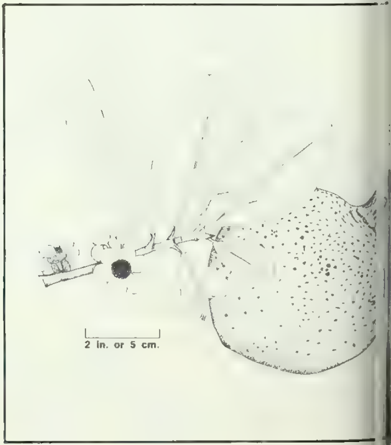


Mammea americana **L.** **Man**
Family: Guttiferae **Mammee-ap**

Handsome, columnar evergreen with white flowers and edible fruit.

Uses: Shade, ornament, and fruit in gardens and parks.
Features: Grows in poor soils if moisture is available. Has erect trunk w dense crown. Also withstands wind.
Limitations: May become too large.
Description: Leaves glossy green, thick, and leathery. Flowers large fragrant, borne on twigs mostly in back of the leaves and lasti 1 to 2 weeks. Fruit with thick skin and firm bright yellow o reddish flesh with white sap. Flowering from May to Octob and with fruit during most of the year. Bark contains pale yell latex.
Rate of growth: Slow.
Mature height: 20 to 65 ft (6 to 20 m).
Crown diameter: 20 ft (6 m).
Remarks: Native to Puerto Rico. Propagated by seeds or wildlings. F can be eaten raw or in pies and preserves, but should be use moderation because various parts of the plant are poisonous guinea pigs or insects. Flowers attract bees.





angifera indica L. **Mango**

amily: Anacardiaceae

vergreen shade tree bearing delicious tropical fruit.

ses: Shade and fruit tree around houses and along highways.

eatures: Has stout trunk and dense, round crown. Flowers and young leaves are attractive. Grows on any soil and withstands wind.

mitations: Fruit flies and a rust fungus on the flowering branches are a problem in wet areas. Fallen fruit causes litter if not picked up. Some people are allergic to the sap and break out with a rash around the mouth and on the face, sometimes just from being near the tree.

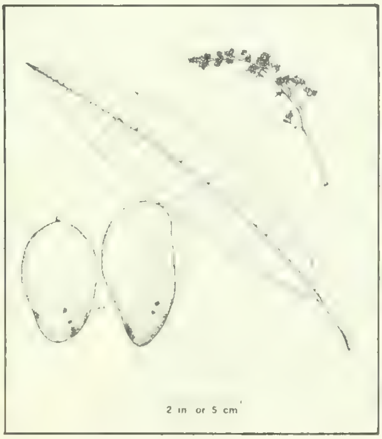
escription: Leaves dark green, drooping in conspicuous red-brown clusters when first produced. Flowers fragrant, yellow-green to pink; in large, showy terminal clusters. Fruit on hanging stalks, varying in size and color and quality of flesh. Flowering mainly from winter to spring and with fruits maturing from May to September.

ate of growth: Moderate.

ature height: 20 to 65 ft (6 to 20 m).

own diameter: 40 ft (12 m).

emarks: Native to tropical Asia. Can be propagated by seed, but budding or grafting is recommended to get superior varieties and varieties resistant to diseases and insects. Around houses should be planted in backyard to avoid stone throwing and pilferage of fruit. Should not be used as a street tree unless arrangements are made to pick up the fruit.



***Manilkara zapota* (L.) v. Royen** **Nisper**
Family: Sapotaceae **Sapodil**

Evergreen with dense crown and delicious fruit; good for dry areas.

Uses: Shade, ornament, and fruit in gardens and along streets.

Features: Grows in most soils including alkaline soils and marl hardpan but grows best on sandy loam with moderate moisture. Withstands drought and strong winds.

Limitations: Root system may spread over ground in shallow soils. Bat relish the fruit and stain building walls with their urine when the come in groups to feed. So near limestone hills or other area where bats are common, trees should not be planted close t buildings.

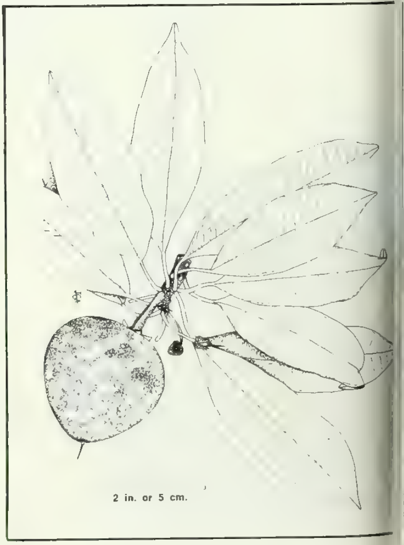
Description: Leaves shiny green, clustered at ends of twigs. Flowers inconspicuous. Fruit brown and rough-skinned, containing sweet, juicy pulp that is eaten raw or made into syrup and preserves. Flowering and fruiting nearly throughout the yea The bark yields a white latex that is the chief source of chewir gum.

Rate of growth: Slow.

Mature height: 50 ft (15 m).

Crown diameter: 20 ft (6 m).

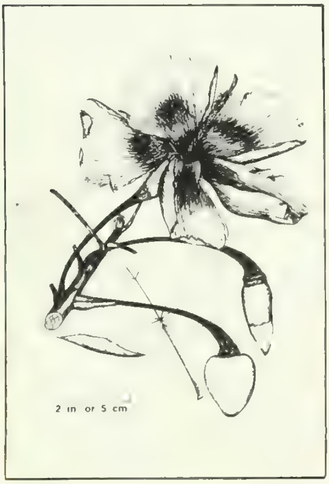
Remarks: Native to southern Mexico and Central America. Propagated b seeds, or by grafting and budding to get superior varieties. Responds well to pruning, so crown can be shaped to keep i low for easy fruitpicking.

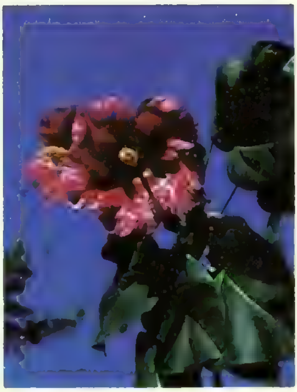


ontezuma speciosissima Sessé + Moc. **Maga**
amily: Malvaceae

arge, red, bell-shaped flowers on evergreen that is Puerto Rico's own.

ses: Shade and ornament in gardens.
atures: Grows in most zones and on most soils in Puerto Rico if moisture is available.
mitations: Large leaves and flowers create some litter. Branches may break in strong winds but grow back quickly.
scription: Leaves slightly thickened and yellow-green. Flowers solitary at leaf bases, only one at a time opening on a twig. Fruit green, fleshy or leathery, rounded and pointed at tip. Flowering and fruiting throughout the year.
te of growth: Moderate.
ture height: 30 to 50 ft (9 to 15 m).
own diameter: 20 ft (6 m).
marks: Native only to Puerto Rico. Propagated by seeds (which lose their viability quickly) and cuttings. Should be pruned to develop a regular crown; pruning also enhances flowering.





Muntingia calabura L. **Cap**
Family: Elaeocarpaceae

Fast-growing tree for ornament and shade in new subdivisions.

Uses: Rapid fill-in and quick shade for new or open areas, should replaced eventually with something that grows more slowly is more permanent.

Features: Grows rapidly in full sunlight, adaptable to dry soils but d best where moisture is available. Evergreen with long, slen spreading branches and many lateral twigs.

Limitations: Roots will grow into septic systems if planted too close. many fruits may be a litter problem and will stain tile or cem patios. Strong winds may break branches or uproot the tr

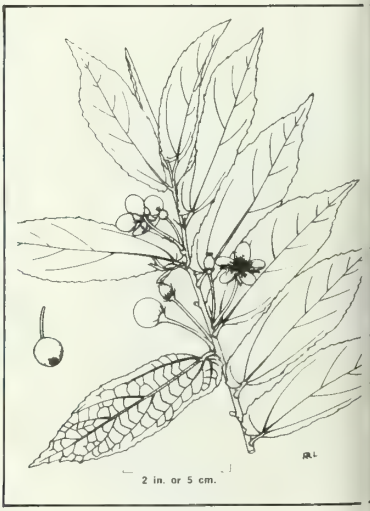
Description: Leaves alternate in 2 rows on twigs. Flowers white, 1 to 3 stalks at base of leaves. Fruit fleshy, edible, reddish to yellowish. Flowering and fruiting throughout the year.

Rate of growth: Rapid. Tree only lasts about 10 years.

Mature height: 25 ft (7.5 m).

Crown diameter: 25 ft (7.5 m).

Remarks: Native to southern Mexico, Central America, and part of t West Indies, but not to Puerto Rico. Propagated by cuttings 6-ft (2 m) branch about 1 inch (2.5 cm) in diameter will grow be a 20 by 20 ft (6 by 6 m) tree covered with fruit within 2 ye



Parkinsonia aculeata L. **Palo de rayo**
Family: Leguminosae **Jerusalem-thorn**

Small, spiny tree with yellow flowers.

Uses: Special effects where a small tree is needed, especially in dry and coastal areas. Often planted along roads or as a spiny living hedge or fence.

Features: Withstands salt spray and wind, and grows well on poor, dry, or sandy soil if soil is well-drained. Open growth, feathery drooping foliage, and yellow flowers make striking contrast.

Limitations: Thorns on stem at base of leaves. Pods may cause litter problem.

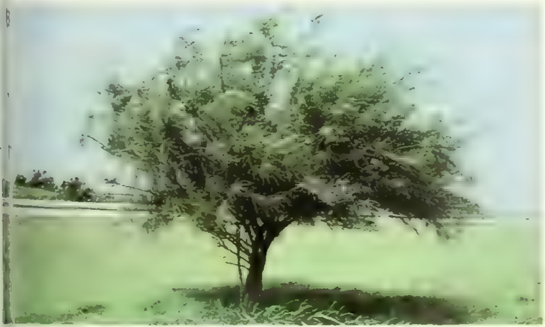
Description: Leaves consist of long, yellow or blue-green strips bearing tiny leaflets that soon fall off, but the strips and green bark keep tree looking fresh and green. Flowers fragrant and showy in loose clusters. Fruit a brown pod narrowed between the seeds. Flowering and fruiting throughout the year.

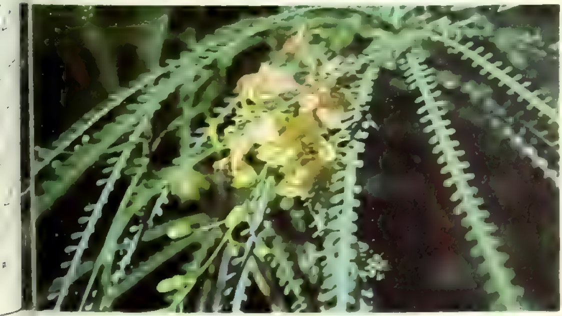
Rate of growth: Rapid. Tree lasts only about 15 years.

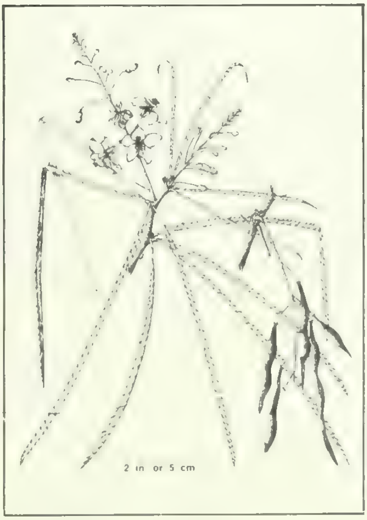
Mature height: 10 to 20 ft (3 to 6 m).

Crown diameter: 10 ft (3 m).

Remarks: Native to Mexico and southwest United States. Propagated by seeds or cuttings. Pruning after flowering reduces litter from pods and improves appearance.







Peltophorum inerme (Roxb.) Naves **Flamboyán amarill**
Family: Leguminosae **Yellow flamboya**

Handsome, spreading tree with dense, dark-green, feathery foliage and showy, rusty-yellow flowers.

Uses: Shade and ornament for gardens and lawns and along roadsides.

Features: Grows on both moist and dry soils. Provides good shade excep in dry season when the leaves fall.

Limitations: Root system deep, but tree is so large that it may be blown over by hurricane-force winds. Also, because of spreading crown, should not be planted close to structures.

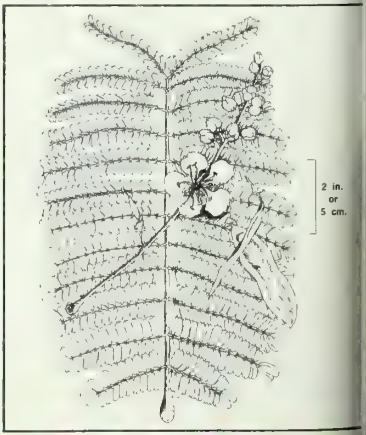
Description: Leaves doubly compound with many small leaflets that do no produce much litter. Flowers fragrant, in branched terminal clusters, with rusty-brown hairs on twigs. Fruit a flat reddish-brown pod. Flowering from April to September, usual at least twice and with flowers lasting 3 to 4 weeks each time and with pods on tree most of year.

Rate of growth: Rapid.

Mature height: 30 to 65 ft (9 to 20 m).

Crown diameter: 40 ft (12 m).

Remarks: Native to tropical southeast Asia. Propagated by seeds. Flowers can be cut for indoor decoration. Appearance of tree can be improved by light pruning to remove old pods.



thecellobium arboreum (L.) Urban **Cojoba**

amily: Leguminosae

pright tree with spreading crown of dark-green, feathery foliage.

ses: Shade and ornament in gardens and along roads.

atures: Grows in good, moist soil but not in wet, heavy soils or in very dry areas. Provides medium shade except during the dry season when it loses leaves for a brief period.

Lmitations: Should not be planted close to structures because roots close to the surface may cause problems.

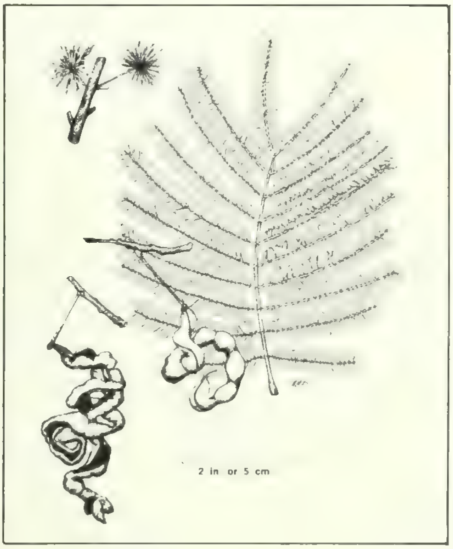
scription: Leaves doubly compound with many pairs of small shiny leaflets that do not produce much litter. Flowers in whitish puffballs at leaf bases. Fruit a coiled or curved red pod, splitting open to expose black seeds hanging on short threads. Flowering in spring with pods maturing in summer and flowering and fruiting again in fall.

te of growth: Moderate.

ture height: 30 to 50 ft (9 to 15 m).

Cown diameter: 20 ft (6 m).

marks: Native to Puerto Rico. Propagated by seeds, which must be collected and sown promptly because they are rapidly destroyed by weevils.



Plumeria rubra L. **Frangipa**

Family: Apocynaceae

Fragrant, waxy, long-lasting red or white flowers, used for garlands an decorations.

Uses: For decorative flowers in gardens, courtyards, patios, cemeteries, planting boxes, and other restricted areas.

Features: Grows in poor soils and dry conditions, but does not do well i poorly drained or wet areas. Tolerates some salt spray. Ha very open crown of few stout, fleshy, spreading branches. Flowers when very young, and often flowers almost all yea long except between March and May.

Limitations: May lose its leaves for up to 2 months during dry season Milky juice is reported to be poisonous in large quantities. large caterpillar sometimes repeatedly defoliates this tree, an a yellow rust on the leaves may also cause them to fall prematurely.

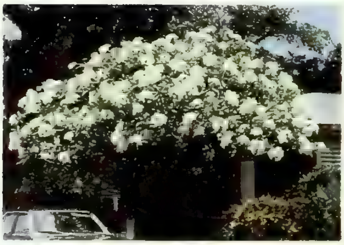
Description: Leaves shiny green, crowded at apex of twigs. Flowers lar and tubular, in flat-topped terminal clusters with center flowe opening first. Fruit a paired, brown, leathery pod. Flowering an fruiting nearly throughout the year. Milky juice flows freely fro cut or broken stems.

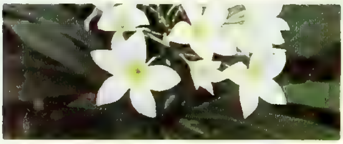
Rate of growth: Rapid. Tree lasts about 30 years.

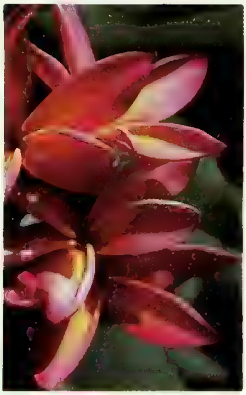
Mature height: 15 to 25 ft (4.5 to 7.5 m).

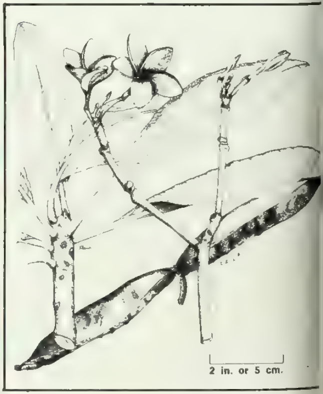
Crown diameter: 15 ft (4.5 m).

Remarks: Native to southern Mexico and Central America, but widel cultivated in the tropics. Propagated by cuttings, which shou be left in a dark, cool spot for at least 48 hours before plantin There are many hybrids and varieties of this species; in Puer Rico, trees with reddish flowers or with white flowers havin yellow centers, are most common.









rocarpus indicus Willd. **Pterocarpus**
mily: Leguminosae **India padauk**

ge ornamental and shade tree with a dense, broad crown of drooping nches.

es: Parks, gardens, and avenues where there is room for the roots.

atures: Grows well in most soils but does best in deep, well-drained soils in humid areas. Nearly evergreen, but sheds most of its leaves for a short time in the spring.

itations: Although it has a deep root system and is relatively wind firm, it often develops superficial roots that can damage sidewalks. The dense shade keeps most other plants from growing beneath it. The falling leaves and pods may cause a litter problem.

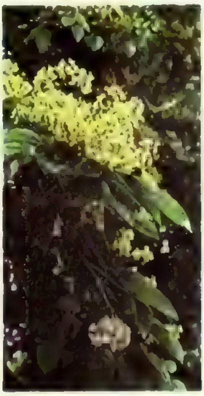
scription: Leaves composed of 7 to 11 leaflets, shiny green to yellow-green. Flowers yellow, pea-shaped, fragrant, in showy lateral clusters but lasting less than a week. Fruit a round, flattened pod surrounded by a wing; green at first but turning brown as it matures. Flowering in June and July, often several times, with fruits maturing in late summer but remaining on tree most of year.

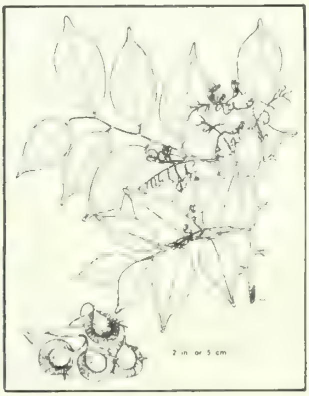
e of growth: Rapid.

ture height: 60 ft (18 m) or more.

wn diameter: 45 ft (13.5 m).

narks: Native to southeast Asia. Propagated by seeds and cuttings. Flowers attract bees. Young plants often have poor form and need staking and pruning until a crown develops. A related species, *Pterocarpus macrocarpus* Kurz (pterocarpus, Burma padauk), which is larger and has larger pods, is occasionally planted in Puerto Rico.





Roystonea borinquena O. F. Cook **Palma**
Family: Palmae **Puerto Rico royalp**

Puerto Rico's own royalpalm for stately effects.

Uses: Street planting, gardens, parks, and roadsides. Most effec when several are planted in a row or group.

Features: Grows throughout Puerto Rico on most soils including po drained ones, but needs moisture.

Limitations: Old leaves, which fall off complete with basal sheath 3 times a year, can be dangerous for passersby and cars in pu areas and may present a disposal problem.

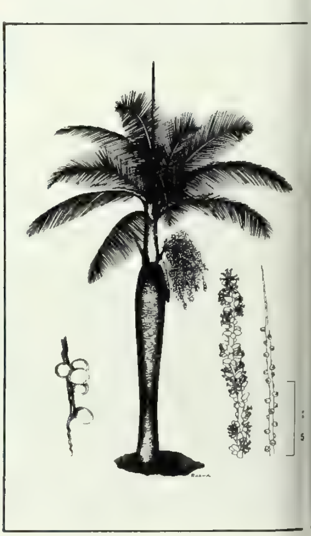
Description: Tall palm with smooth, gray trunk constricted above base swollen again higher up, with narrow, light-green column of l sheaths below spreading crown of feathery leaves. Much branched inflorescence arises at base of green column a bears whitish flowers and small, brown fruits. Flowering a fruiting throughout the year.

Rate of growth: Moderate.

Mature height: 30 to 60 ft (9-18 m).

Crown diameter: 25 ft (7.5 m).

Remarks: Native to Puerto Rico and St. Croix. Propagated by seed related species, *Roystonea regia* (H.B.K.) O. F. Cook (pa real cubana, Cuban royalpalm) from Cuba has a tall but swollen trunk and is also sometimes planted in Puerto Ri Another palm with a bulging trunk, *Acrocomia media* O. F. C (corozo, prickly palm, Puerto Rico acrocomia), is shorter has a spine-covered trunk and no sheaths below the lea



ix babylonica L. **Sauce llorón**
mily: Salicaceae **Weeping willow**

st-growing, small tree with weeping effect for wet areas.

es: Around pools and streams and as a graceful accent in gardens.

atures: Grows best in low, wet areas; withstands periodic flooding and will grow in dry areas if watered regularly. Evergreen except under very dry conditions.

itations: Root system is shallow and will clog sewers and water pipes. Branches easily broken by wind.

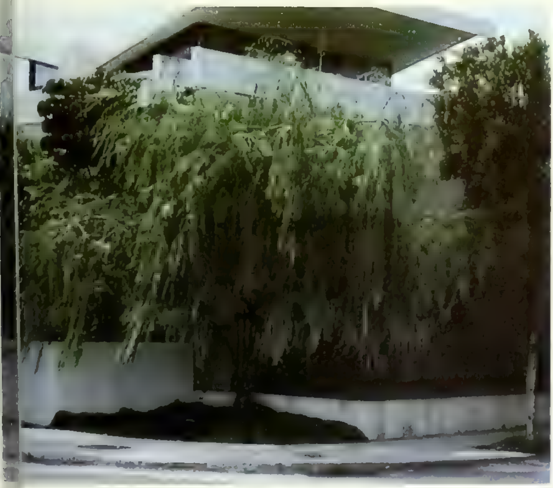
scription: Leaves narrow, with slight but distinctive odor when crushed; on long, slender drooping twigs. Male and female flowers in catkins on different trees, but apparently not flowering in Puerto Rico.

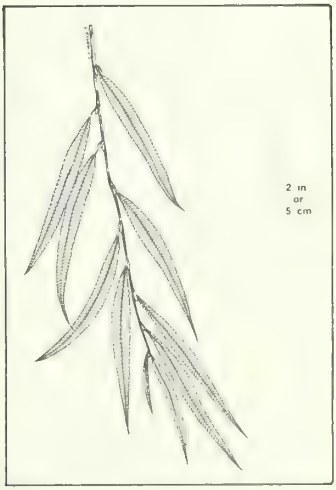
e of growth: Rapid. Tree lasts only about 15 years.

ture height: 25 ft (7.5 m).

wn diameter: 20 ft (6 m).

narks: Native to China. Propagated by stem cuttings, easily rooted and transplanted.





Sterculia apetala (Jacq.) Karst. **Anacagü**
Family: Sterculiaceae **Panama-t**

Tall tree with large trunk and dense, wide-spreading crown.

Uses: Shade and ornament in large areas and along roadsides.

Features: Grows in dry climates if soil is deep and has moisture. Provid good shade and crown is high enough to let breezes blow through underneath.

Limitations: Needs large area to grow in, and develops large root syste and buttresses. Pods contain irritating hairs when they matu Branches are somewhat brittle but recover quickly after w damage.

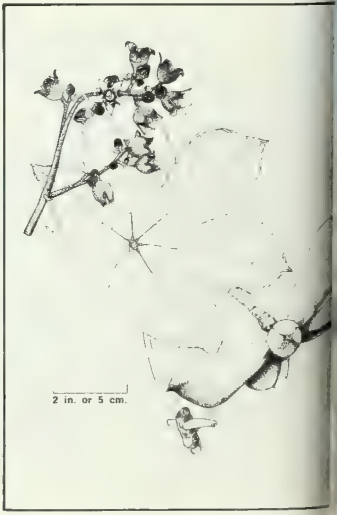
Description: Leaves palmately lobed, leathery and pleated, densely wo on underside. Flowers in long, branched clusters; bell-sha and yellow tinged with red or purple. Fruit composed of 5 fewer hard, brown, spreading pods. Flowering in spring a often again in summer or fall for about 1 month each time, po usually maturing in spring.

Rate of growth: Moderate.

Mature height: 60 ft (18 m) or more.

Crown diameter: 40 ft (12 m) or more.

Remarks: Native from southern Mexico to northern South America. Propagated by seeds. A related species, *Sterculia foetida* (anacagüita, hazel sterculia), has 5 to 11 long-pointed, palmately-arranged leaflets and reddish or purplish flowe whose unpleasant odor makes it undesirable as an ornamen



etenia macrophylla King **Caoba hondureña**

amily: Meliaceae **Broadleaf mahogany**

aight trunk and dense crown for shade and ornament.

es: Gardens, parks, and roadsides.

eatures: Grows on most soils if moisture is available, and will withstand drought once it has become established.

itations: Trunk develops buttresses and surface roots, so should not be planted close to buildings or sidewalks. Also suffers windthrow or breakage from hurricane-force winds. A boring insect kills the leading shoots of young trees, but the damage can be minimized by pruning to develop crowns that are bushier and better for shade.

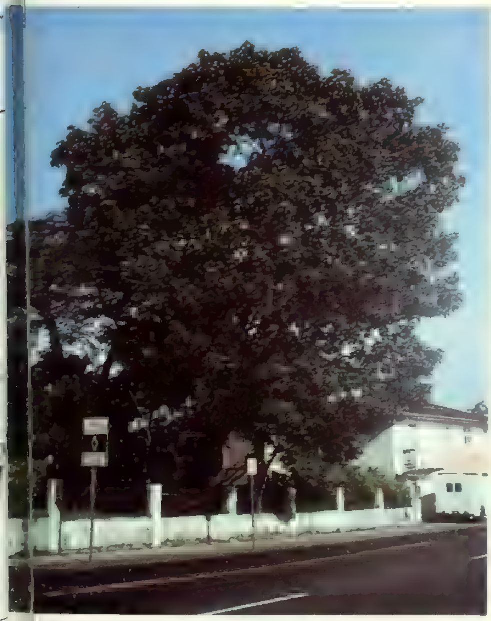
escription: Leaves with 6 to 12 pairs of dark-green, shiny leaflets. Trees leafless for a short period in the spring. Flowers fragrant but inconspicuous. Fruit a brown, woody, erect, pear-shaped capsule. Flowering in May and June with fruit maturing in late fall.

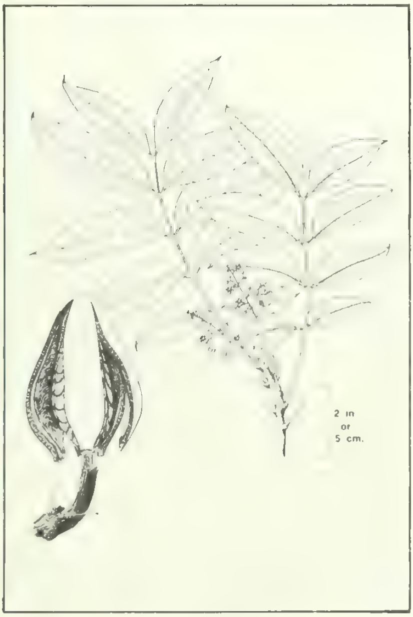
te of growth: Rapid.

ture height: 60 ft (18 m) or more.

rwn diameter: 40 ft (12 m).

emarks: Native to tropical Central and South America. Propagated by seeds or wildlings. Produces a valuable wood for furniture, veneer, and turned articles.





Swietenia mahagoni Jacq. **Caoba dominic**
Family: Meliaceae **West Indies mahoga**

Dense-crowned tree for dry and coastal areas.

Uses: Shade and ornament in gardens and along roads.

Features: Grows on a wide variety of soils from coral rock to sand. Withstands drought, wind, and salt spray. Usually has a sh trunk and spreading crown.

Limitations: Although it does not grow rapidly, the trunk tends to deve buttresses and surface roots, so should not be planted close buildings or sidewalks. A shootborer damages young trees, b is not a serious problem in Puerto Rico and the Virgin Island although it is in Hispaniola.

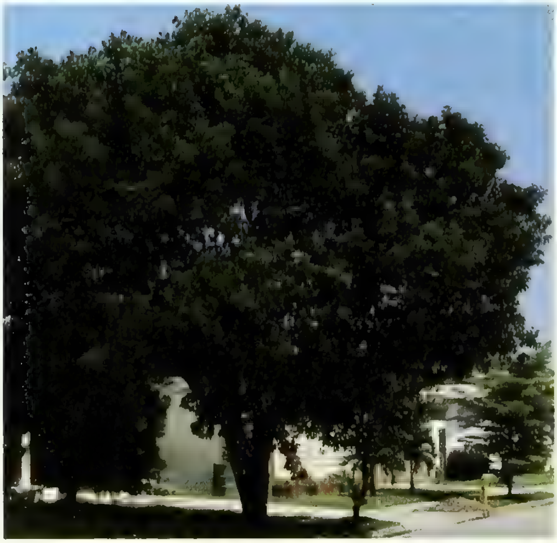
Description: Leaves with 4 to 10 pairs of shiny green leaflets. Trees leaf a short time in the spring. Flowers inconspicuous. Fruit a d brown, woody, erect, pear-shaped capsule. Flowering fro January to March.

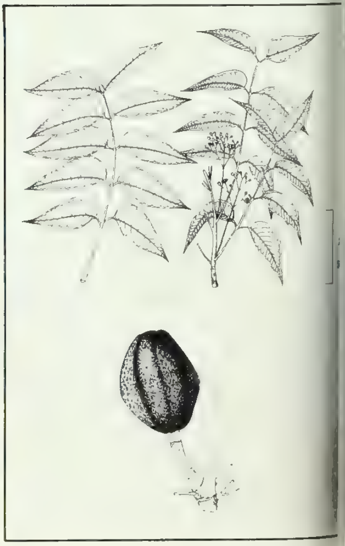
Rate of growth: Moderate.

Mature height: 40 to 60 ft (12 to 18 m).

Crown diameter: 40 ft (12 m).

Remarks: Native from southern Florida to Cuba, Jamaica, and Hispaniola. Propagated by seeds. Produces one of the worl premier cabinet woods. A natural hybrid between this spec and _Swietenia macrophylla_, discovered on St. Croix and known as "medium-leaf" mahogany, is faster-growing an therefore a better choice for planting except in very dry are





ebuia heterophylla (DC.) Britton **Roble blanco**
nily: Bignoniaceae **White-cedar**

rfuse, showy, pink flowers on widely adapted native species.

s: Ornament around houses and along roads.

tures: Grows on any soil type and is particularly well adapted to poor or degraded soils if moisture is available. Covered for 2 to 4 weeks with masses of flowers in the spring while the tree is leafless and sometimes again in the fall. Root system not troublesome so tree can be planted in confined areas.

itations: Branches often deformed to a "witches-broom" appearance by a virus transmitted by a leaf hopper. This insect also causes the leaves to turn yellow and fall prematurely during long dry spells.

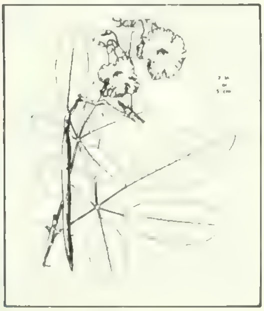
cription: Leaves with 5 or fewer large, palmately arranged leaflets that are usually smaller in dry areas. Flowers abundant over the crown in small clusters, each only lasting a few days and carpeting the ground when they fall, usually pink but white or purple on some trees. Fruit a dark-brown, cigar-shaped pod. Flowering in spring, often again in fall, and sporadically throughout the year, and with fruit all year.

of growth: Slow.

ure height: 60 ft (18 m).

wn diameter: 20 ft (6 m).

arks: Native to Puerto Rico and the Virgin Islands. Propagated by seeds or wildlings. Young trees often flower within 1 or 2 years after planting. The wood has been used for construction and furniture. Because of the witches-broom disease, *Tabebuia rosea* (Bertol.) DC. (roble venezolano, pink trumpet-tree), which has pink to reddish flowers, or *Tabebuia glomerata* Urban (roble amarillo, yellow poui), which has yellow flowers, may be preferable if they are available. However, they are not as well adapted to poor soils.



***Tamarindus indica* L.** **Tamari**
Family: Leguminosae **Tamar**

Dense, feathery foliage, with fruit for refreshing drink.

Uses: Shade, ornament, and fruit in gardens and parks.

Features: Grows on poor soils and in dry areas, also in wetter areas if soil is well drained. Has wide crown that casts dense sha although the tree may lose many of its leaves during severe seasons. The pulp in the pods makes a refreshing drink. Highly resistant to wind.

Limitations: Pods may create messy litter. The dense shade keeps m other plants from growing beneath it. Should not be plant close to buildings or pavements because of the spreadin crown and the trunk, which eventually gets quite large.

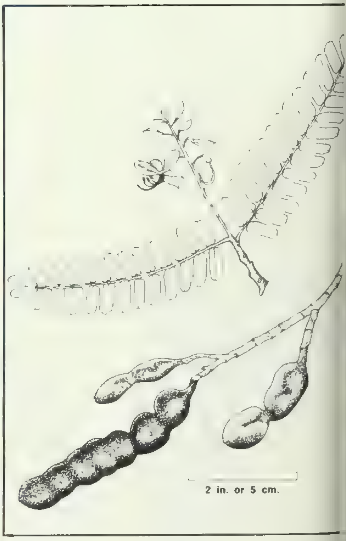
Description: Leaves with 10 to 18 pairs of blue-green leaflets. Flower small clusters, pale yellow, and not showy except from cl by. Fruit a dark-brown pod constricted between the seeds. Flowering from spring to fall and fruiting from winter to spr

Rate of growth: Slow.

Mature height: 40 ft (12 m).

Crown diameter: 30 ft (9 m).

Remarks: Native to Old World tropics. Propagated by seeds. Growt seedlings often rapid for first 8 to 10 ft (2.5 to 3 m).



ecoma stans (L.) H.B.K. **Roble amarillo**
amily: Bignoniaceae **Ginger-thomas**

howy yellow flowers on small tree for dry areas.

ses: Along roadsides, in fences and privacy screens, and similar places where a small tree is needed.

eatures: Grows almost anywhere, including poor soils, but does best in well-drained soils in dry areas and with full sun. Often more of a bush than a tree, with small clusters of long-lasting flowers.

mitations: Should not be planted close to buildings, sidewalks, or underground utilities because the roots and crown spread very quickly. Should be pruned after flowering to restrain the spread and to maintain dense foliage and induce further flowering. Branches somewhat brittle but tree recovers quickly after wind damage.

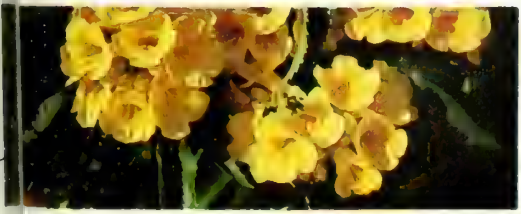
escription: Leaves with 5 to 13 saw-toothed leaflets. Flowers trumpet-shaped and slightly fragrant. Fruit a narrow, dark-brown, cigar-shaped pod. Flowering and fruiting nearly throughout the year.

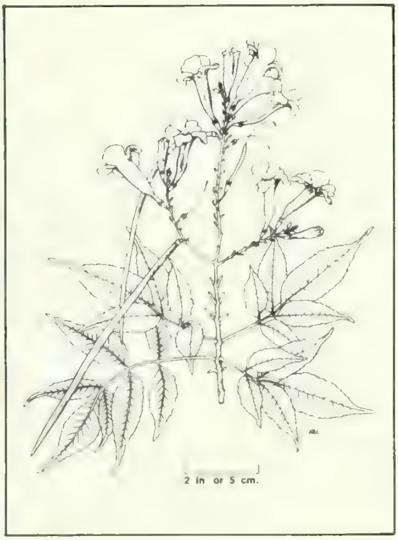
te of growth: Rapid.

ature height: 10 to 25 ft (3 to 7.5 m).

own diameter: 10 ft (3 m).

emarks: Native to Puerto Rico and the Virgin Islands; official flower of the U. S. Virgin Islands. Propagated by seeds or soft greenwood cuttings. Grows best when young and should be replanted after 10 to 15 years.





***Terminalia catappa* L.** **Almendra**
Family: Combretaceae **Indian-almond**

Large leaves, pagoda-like branching, and edible seeds.

Uses: Shade and ornament along roads and in beach areas.

Features: Grows in most soils, both acid and alkaline, as long as moisture is available, and withstands salt spray. Leaves turn red before falling. Because the tree loses some leaves throughout the year and nearly all in March or April, it usually has at least some colored leaves. Erect trunk has horizontal branches in whorls at different levels.

Limitations: Should not be planted close to buildings or sidewalks because the trunk becomes buttressed. Falling leaves and fruit may create litter problem. Strong winds may damage branches, but tree recovers quickly. Insects attack the leaves during dry weather, causing them to look grayish or silvery and to fall prematurely.

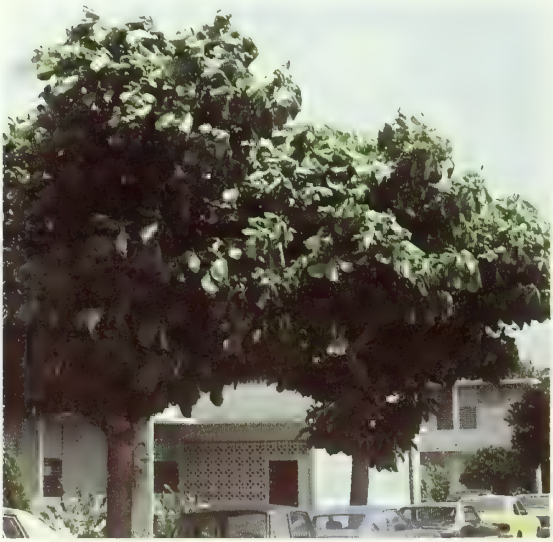
Description: Leaves leathery and somewhat shiny, crowded close together near ends of twigs. Flowers small and slightly fragran in long, narrow clusters. Fruit light brown and slightly flattened with fibrous husk containing edible kernel that tastes like almond. Flowering and fruiting nearly throughout the year.

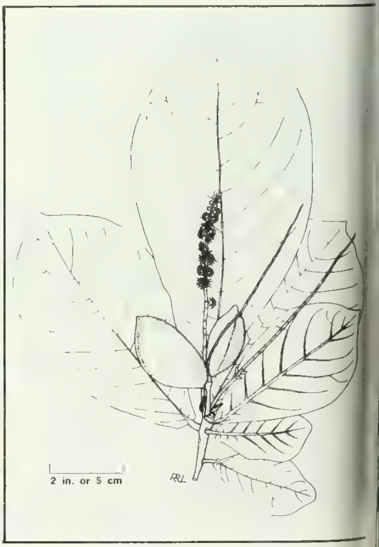
Rate of growth: Rapid.

Mature height: 50 ft (15 m).

Crown diameter: 30 ft (9 m).

Remarks: Native to East Indies. Propagated by seeds.





hespesia populnea (L.) Soland. Emajagüilla

amily: Malvaceae **Otaheita**

mall, yellow-flowered tree for beaches and poor soils.

ses: Ornament, some shade, and screening, especially near the ocean but also in gardens and along streets.

eatures: Highly salt-resistant. Will grow on marl, coral rock or sand, and on sand dunes, pumped-in fills, and swampy areas. Makes a good screen.

imitations: Sometimes develops, especially in dry areas, sprawling lower branches that should be pruned unless the tree is being grown as a hedge.

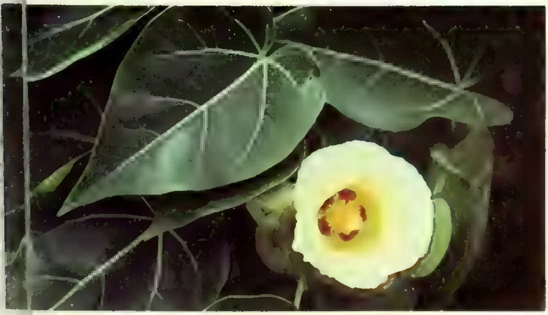
escription: Leaves heart-shaped and dark shiny green. Flowers pale yellow with purplish base, lasting only 1 day and turning all purple. Fruit hard and dry, gray, rounded, 5-ridged, and flattened. Flowering and fruiting from spring to fall.

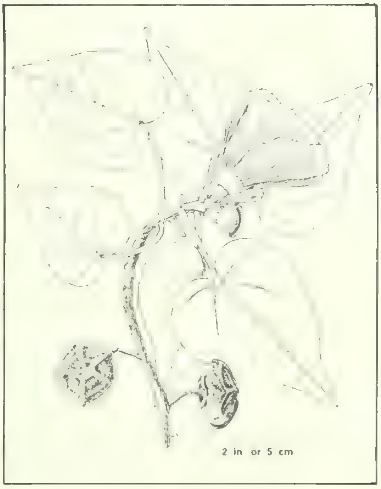
ate of growth: Rapid to moderate. Tree lasts about 20 years.

ature height: 30 ft (9 m).

rown diameter: 15 ft (4.5 m).

emarks: Probably native to Old World, but now widely planted and naturalized throughout the tropics. Propagated by seeds, or cuttings of semimature wood. Bark is very fibrous and will peel down in strips if pruning is not done carefully.





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Appendix

her sometimes-planted species and their limitations:

1 *Anacardium occidentale* L.; pajuil, cashew — limited adaptability and slow growth.

2 *Bambusa vulgaris* Schrad.; bambú, common bamboo — hard to control spread.

3 *Brassaia actinophylla* Endl.; scheflera, umbrella-tree — form not very attractive except when young, needs repeated pruning.

4 *Calophyllum inophyllum* L.; kamani — not as attractive or versatile as *Calophyllum calaba* because of its long branches and heavy crown.

5 *Cassia fistula* L.; cañafistula, golden-shower — when not in flower, large pods and straggling branches make it unattractive.

6 *Cochlospermum vitifolium* (Willd.) Spreng.; rosa imperial, Brazilian-rose — poor form and unattractive appearance when not in flower.

7 *Cyathea arborea* (L.) J.E. Smith; helecho gigante, tree fern — limited adaptability because it needs constant moisture.

8 *Enterolobium cyclocarpum* (Jacq.) Griseb.; guanacaste, earpod-tree — giant tree susceptible to root disease.

9 *Ficus lyrata* Warb.; fiddle-leaf fig. — considered less attractive than *Ficus nekbuda*.

0 *Ficus retusa* L.; laurel de la India, India-laurel fig. — short-lived and difficult to remove, thrips insects deform leaves and irritate eyes of people beneath crown.

1. *Gliricidia sepium* (Jacq.) Steud.; mata-ratón, mother-of-cocoa — less attractive than *Cassia javanica,* form shrubby and straggly.

2. *Jacaranda mimosifolia* D. Don; jacaranda — does not generally flower well, needs cooler and drier climate than that of Puerto Rico and the Virgin Islands.

3. *Melaleuca quinquenervia* (Cav.) S.T. Blake; cayeputi, cajeput-tree —usually has very scraggly form.

4. *Melia azedarach* L.; alelaila, chinaberry — frequently with poor form. poisonous.

5. *Pimenta racemosa* (Mill.) J.W. Moore; malagueta, bay-rum-tree — very slow growth.

6. *Pithecellobium saman* (Jacq.) Benth.; samán, raintree — large attractive tree but very susceptible to root disease.

7. *Plumeria alba* L.; alelí, milktree — less attractive than *Plumeria rubra*.

8. *Sabal causiarum* (O.F. Cook) Beccari; palma de sombrero, Puerto Rico palmetto — slow growth, less attractive than *Roystonea borinquena*.

19. *Salix humboldtiana* Willd.; sauce, Humboldt willow — loses vigor aft
few years and then has poor appearance.
20. *Spathodea campanulata* Beauv.; tulipán africano, African tulip
—easily broken by wind, roots may damage sidewalks and buildi
sprouts from roots, and is likely to seed into open areas.
21. *Tibouchina granulosa* (Desr.) Cogn.; glorybush — widespread
adaptability not yet proven.

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escribes and illustrates forty-six tree species useful for shade and ament in Puerto Rico and the Virgin Islands. Information is also provided out planting, maintenance, and appropriate use of trees in urban areas.

ditional keywords: Tree planting, urban forestry.

Tis paper mentions the use of pesticides. If pesticides are handled, aplied, or disposed of improperly, they may be injurious to humans, dmestic animals, desirable plants, and pollinating insects, fish, or oher wildlife, and may contaminate water supplies. Use pesticides oly when needed and handle them with care. Follow the directions ad heed all precautions on the container label.

Sme states have restrictions on the use of certain pesticides. Check yur State and local regulations. Also, because registrations of psticides are under constant review by the U.S. Environmental Potection Agency, consult your local agricultural extension agent to b sure intended use is still registered.

U.S. Department of Agriculture
Forest Service
General Technical Report SO-28

Changes in Wood Processing and Use Have Influenced the Likelihood of Beetle Infestations in Seasoned Wood

Lonnie H. Williams

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SUMMARY

Fewer houses are being built with crawl spaces and more houses have central heating and air-conditioning, so the number of anobiid beetle infestations should decline. The likelihood of lyctid infestations in domestic hardwoods has been decreased by improved processing and marketing, but increased imports of tropical hardwoods likely will increase the frequency of infestations. More imports of unseasoned hardwood crates, pallets, and dunnage also may increase the probability of bostrichid infestations. Incidence of infestations by old house borers probably will change little. Trends in wood use suggest the present nationwide incidence of wood-destroying beetle infestations in structures ranks: anobiids, lyctids, old house borers, and bostrichids. Rankings of anobiids and lyctids, however, probably will be reversed in the near future. Lyctids already create the greatest replacement expense.

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1980

Changes in Wood Processing and Use Have Influenced the Likelihood of Beetle Infestations in Seasoned Wood

Lonnie H. Williams

INTRODUCTION

Many beetle species in the families Anobiidae, Lctidae, Bostrichidae, and Cerambycidae infest ssoned wood during processing or use. Beetles o each family, however, usually need wood of diferent types or in different conditions to scessfully infest it. Depending upon the type of betle involved and how the wood is stored, pcessed, finished, or used, infestations may ocur during processing, manufacturing, and mrketing, or years after wood is in use. Also, beause infested wood is sometimes used for fished products, infestations often occur where adlt beetles would not be present to start them or wre temperature, moisture, and other factors ar not favorable.

For each beetle family I discuss how changes in ood processing and manufacturing technology an in supply and demand have affected the liklihood of beetle infestations and needs for prvention or control.

ANOBIIDAE

Cditions Influencing Infestations

Many anobiid species attack seasoned hardwod and softwood. In the south, *Xyletinus peatus* (Harris) is the most common beetle that insts wood in use (Williams and Smythe 1978). Obuildings and improperly stored lumber are ocsionally infested, but most infestations begin whn adult beetles fly to exposed wood in crawl spes beneath houses. In crawl spaces beetles fin moderate temperatures and high relative huidities, conditions that favor infestation. Duing mid-April through September—when adlt *X. peltatus* beetles are emerging, mating, layg eggs, and small larvae are establishing themselves in wood—ambient temperatures in crawl spaces on the Mississippi Gulf Coast usually are 23-29°C and relative humidities are 70-90 percent. So, emergence and infestation are synchronized with favorable conditions (Williams and Waldrop 1978).

The likelihood of an anobiid infestation depends primarily on whether unfinished wood is exposed in a damp environment such as a crawl space. Among crawl spaces, the likelihood and particularly the severity of infestations are influenced by species, density, and moisture of wood, and by reconstituted products such as plywood. Wood moisture in crawl spaces varies with local climates, annual rainfall, surface water drainage, soil moisture, ventilation, and use of heating, air-conditioning, soil covers, and insulating materials with vapor barriers.

Changes Influencing Infestations

Construction Type.—In 11 southern States, the number of single-family dwellings with crawl spaces was about 700,000 less in 1970 than in 1960 because more houses with crawl spaces were demolished than were built (table 1). In 1970, however, there were about 590,000 more houses with basements and about 3,000,000 more with slabs.

In houses with slab or full basement construction, infestations of Anobiidae are rare because unfinished, untreated wood is not exposed for beetles to attack. So, about 47 percent of all houses essentially are "immune" to anobiid beetle attacks (table 1). The number of crawl spaces declined in all States but North and South Carolina. Apparently, many new houses with crawl spaces are still being built in these two States and also in Arkansas, Georgia, and Tennessee (table 1). Construction in coastal areas

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of most States where high humidity favors anobiids probably parallels that observed in Mississippi; though many new houses are being built, most are on slabs.

Many new houses are being built with so-called log-kit construction. Houses built from these kits have a conventional crawl space with presawn, unseasoned southern pine logs for the walls above it. Although logs may receive momentary dip-treatments before use, unfinished, untreated wood will later be exposed by shrinking and cracking as the logs dry. Until treatments giving effective long-term protection are devised, such houses seem very susceptible to infestations of anobiids and other beetles or to decay.

Central Heating and Air-conditioning.—In the 11 States, the percentage of occupied structures with central heating increased from 13.5 percent in 1960 to 31.4 percent in 1970, ranging from about 21 percent in Mississippi to 43 percent in North Carolina. For these years the percentage of occupied structures with central air-conditioning increased 14.2 percent, houses with room units increased 18 percent, and those with no air-conditioning declined from 81.7 percent in 1960 to 49.7 percent in 1970 (table 2). Central cooling and heating systems are being installed in most new homes constructed today, and room units and central systems also are being installed in older homes. Central cooling or heating reduces the humidity in a house, so the wood moisture content is reduced below the critical level for infestation by *X. peltatus* beetles. Therefore, most infestations should be confined to crawl spaces or at least limited in their severity above the first floor.

With many heating and cooling systems, insulation is now being added between floor joists in many crawl spaces, where improper placement of vapor barriers could cause high wood moisture, which favors anobiid infestations. Detection and treatment of such infestations would be difficult and expensive. But if one installs soil covers when adding insulation, moisture problems can be avoided (Amburgey 1978).

Type of Wood Used.—Of all houses in the 11 States by 1970, about 69 percent were built before 1959 and about 27 percent (4.3 million) before 1940 (table 3). Limited construction of houses on slabs before 1940 and existence of only 1.2 million houses with basements by 1960 suggests most of

Table 1.—*Number of single-family dwellings in each of 11 southern States in 1970; number with basement, slab, or crawl space; percentage change from 1960 for each foundation type; and percentage of each type in 1970*

State	Total dwellings		Basements		Slab		Crawl space	
	No.	Change (%)	No.	Change (%)	No.	Change (%)	No.	Change (%)
Alabama	1,114,845	15.2	160,677	59.8	272,630	95.2	681,538	− 6.7
Arkansas	672,967	14.7	52,260	69.6	143,807	132.6	476,900	− 3.6
Florida	2,490,838	41.0	82,237	164.3	1,606,803	92.3	801,798	−13.5
Georgia	1,466,687	25.4	304,813	71.9	359,802	106.9	802,072	− 2.0
Louisiana	1,146,105	17.1	34,701	63.6	421,044	143.2	690,360	−13.6
Mississippi	697,271	10.9	35,103	88.3	152,969	157.4	509,199	− 8.2
North Carolina	1,619,548	22.4	387,055	40.4	313,579	103.8	918,914	+ 2.9
Oklahoma	937,815	15.0	102,872	16.2	316,661	91.0	518,282	− 8.3
South Carolina	804,858	18.6	88,438	57.6	148,561	74.5	567,859	+ 5.7
Tennessee	1,297,000	19.6	368,753	33.7	329,316	54.2	598,931	− 5.2
Texas	3,809,086	20.8	131,486	62.8	1,769,854	121.7	1,907,746	−19.1
Totals and Means	16,057,020	22.0	1,748,395	33.8	5,835,026	106.5	8,473,599	− 7.7

ble 2.—*Use of room or central air-conditioning in occupied single-family dwellings in 1960 and 1970 in 11 southern States*

State	No. occupied dwellings		Method of cooling[1] Central air		Room unit(s)		No air	
	1960	1970	1960	1970	1960	1970	1960	1970
bama	884,116	1,114,791	2.6	15.2	14.1	33.8	83.3	51.0
ansas	523,442	672,970	2.1	14.9	11.8	31.6	86.1	53.5
Fl ida	1,550,414	2,490,777	2.8	23.3	15.4	37.1	81.8	39.6
rgia	1,070,325	1,466,625	1.7	15.4	10.6	27.6	87.7	57.0
isiana	892,344	1,145,973	3.0	20.2	20.1	38.6	76.9	41.2
ississippi	568,070	697,210	1.7	13.5	14.0	34.0	84.3	52.5
h Carolina	1,204,715	1,619,279	1.1	8.9	7.7	23.8	91.2	67.3
homa	734,593	937,827	3.5	18.9	26.2	39.7	70.3	41.4
h Carolina	603,551	804,817	1.4	11.0	10.7	29.1	87.9	59.9
nessee	1,003,301	1,296,928	2.0	12.2	18.5	40.3	79.5	47.5
e s	2,778,116	3,808,916	5.1	27.8	25.3	36.4	69.6	35.8
eans			2.4	16.6	15.8	33.8	81.7	49.7

N nber of dwellings with each type expressed as a percent of total dwellings occupied in 1960 and 1970.

3.—*Age distribution in 1970 of single-family dwellings in 11 southern States*

State	Total No. dwellings in 1970	Percent of total dwellings in each age group 0-10 years	11-20 years	21-30 years	31 + years
la ma	1,114,845	29.6	23.0	16.8	30.6
rk sas	672,967	29.5	19.0	18.4	33.1
lor a	2,490,838	41.2	31.5	12.4	14.9
Geo ia	1,466,687	34.2	22.5	14.7	28.6
ou iana	1,146,105	28.3	24.6	18.8	28.3
is sippi	697,271	29.4	20.2	17.6	32.8
ort Carolina	1,619,548	30.8	22.0	15.6	31.6
kl oma	937,815	26.2	20.9	15.4	37.5
out Carolina	804,858	31.5	22.7	15.8	30.0
en ssee	1,297,000	30.1	22.4	16.2	31.3
exa	3,809,086	30.5	27.4	18.2	23.9
To l and Means	16,057,020	31.2	24.9	16.2	27.0

the 4.3 million houses, now 40 or more years old, have crawl spaces. Thus, about half of the crawl-space houses existing in 1970 were constructed with very dense lumber from large mature trees and should not be severely damaged by anobiid beetles (Williams and Smythe 1978, Williams and Barnes 1979). Most of the remaining crawl spaces, particularly those constructed between 1940 and 1959, contain fast grown southern pine with much springwood, the main food of *X. peltatus* in pine (Williams 1977). Such houses are most likely to be severely infested.

Housing surveys by Phelps (1966, 1971) and unpublished observations from house inspections made by Williams and Smythe suggest that wood and wood products other than southern pine often are present in recent crawl-space construction. For example, western conifers are often used for wall studs and sometimes for floor joists. Also, reconstituted wood products, particularly plywood, are often used for sheathing and subflooring. Apparently, *X. peltatus* beetles cannot successfully infest southern pine or Douglas-fir plywood that contains synthetic resin glues (Williams and Mauldin 1974).[1] Also, in limited tests,[2] western conifers were not infested by *X. peltatus*; significantly, this beetle's distribution does not include states where western conifers grow (Simeone 1962).

Outlook for Prevention and Control

If trends continue for foundation construction, wood products consumption, and central cooling and heating systems usage, then the number of anobiid beetle infestations should decline. This trend and the limited capabilities of these beetles for causing damage suggest expensive preventive measures are not warranted. Infestations are usually confined to softwood floor joists and subflooring where remedial control can be achieved after infestations are detected and usually before replacement of damaged wood is needed (Williams and Smythe 1978, Williams and Barnes 1979). But uncontrolled infestations may become inaccessible in walls and exposed damage (exit holes) may occur within living areas when houses have severe moisture problems (Williams 1973).

Because infestations are inaccessible a because the only approved insecticide giv residual control (0.5 percent lindane wa emulsion registered in about 26 states) cannot used indoors, expensive tent fumigations done. To provide inexpensive controls appropri for anobiid beetle damage capabilities, sa residual insecticides for application in living ar and control by wood moisture reduction n evaluation.

LYCTIDAE

Conditions Influencing Infestations

Lyctid beetles only attack hardwoods th have at least 3 percent starch and pores la enough for the insertion of eggs. As wood a after tree felling, it loses starch by respiration a becomes less susceptible. Any finish such as pa or varnish that fills wood pores will prevent e laying. Lyctid beetles therefore are primar found where unfinished hardwoods a manufactured or distributed, or in hardwo products that have been in use or storage for l than 5 years (Bletchly 1960, Gerberg 1957). M lyctid infestations are introduced within str tures by the use of infested products. T likelihood of infestation varies with sup sources and species of hardwoods and with use preventive procedures during manufacturi These procedures include a sterilization step kiln schedules to kill larvae in incoming sto inspection for infestations, first-in/first-out sto rotation, good woodyard cleanliness includi frequent chipping or burning of scraps, and usi softwood (coniferous) stickers and pall (LaFage and Williams 1979).

Changes Influencing Infestations

Although a reference (USDA 1941) on prevention and control of lyctids in milita operations suggests these beetles once cau serious problems for domestic hardwood c sumers, this is no longer true. Now most domes hardwoods are kiln dried, a process which, properly done, kills all insects within wood. Ki dried wood often is dipped in water-repell sealers that close pores and prevent egg-layi Susceptible domestic woods such as ash, wh oak, pecan, and walnut have become so valua that they are used primarily as veneers. Dry and gluing of veneers also helps prevent attack oods that otherwise might be susceptible. On the hole, improved processing and transportation echnology has minimized lyctid beetle damage in omestic hardwoods.

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[1] Williams, Lonnie H., and Joe K. Mauldin. Unpublished data from study No. FS-SO-2205-11.367 (on file For. Sci. Lab., Gulfport, Miss.)

[2] Williams, Lonnie H. Unpublished test data (on file For. Sci. Lab., Gulfport, Miss.).

Domestic hardwood production has declined nd millwork, molding, plywood, and veneer are o longer listed as major uses of domestic hard-oods.[3] For example, production of domestic ardwood plywood and veneer declined 50 percent om 1950 to 1974 (Phelps 1975). To obtain lentiful supplies of raw hardwoods, U.S. anufacturers now rely on imports from Africa, sia, Latin America, and Southeast Asia. From 50 to 1974, imported hardwood lumber trade creased by about 67 percent and imports of rdwood plywood and veneer increased about 30-ld (Phelps 1975, Stone and Dickerhoof 1977). In 76, the United States imported, mostly from utheast Asia, about 594,560 m^2 of hardwood ywood, veneer, and hardboard valued at cost of out $440 million. About 1,368,800 m^3 of solid rdwood products such as lumber, flooring, and moldings, valued at about $129.6 million were imported, with more than half from Asia and the rest mostly from Latin America.[4]

As in England and Germany where lyctid infestations frequently result from the importation of tropical hardwoods (Bletchly 1960, Cymorek 1977), concomitant increases in lyctid infestations and damage will probably result from the increasing volume and variety of hardwood imported into the United States. Included among the lyctid-susceptible woods commonly being imported are the light-colored, low-density woods with high starch content such as banak (*Virola* spp.), meranti or lauan (*Shorea* spp.), and obeche (*Tripoxylon scleroxylon* K. Schum.). Such woods are now used for millwork, molding, picture frames, paneling, plywood core stock, or specialty products such as shoe heels, and may contain lyctid infestations (fig. 1, 2, 3). Imported hardwoods are particularly vulnerable to lyctid attacks because adult beetles are present during most of the year in the tropics. Also, untreated, un-

Figure 1.—*Door facings of banak heavily infested by* L. brunneus.

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[3] refrath, B. C. (n.d.) The use of benzene hexachloride in the thern hardwood lumber industry. Natl. Manuf. Prod. sn., Washington, D.C.

[4] Potter, P. M. 1978. Personal correspondence to J. P. LaFage, La. State Univ., Baton Rouge, La. Imported Hardwood Prod. Assn. Rep on imported hardwood statistics for 1976.

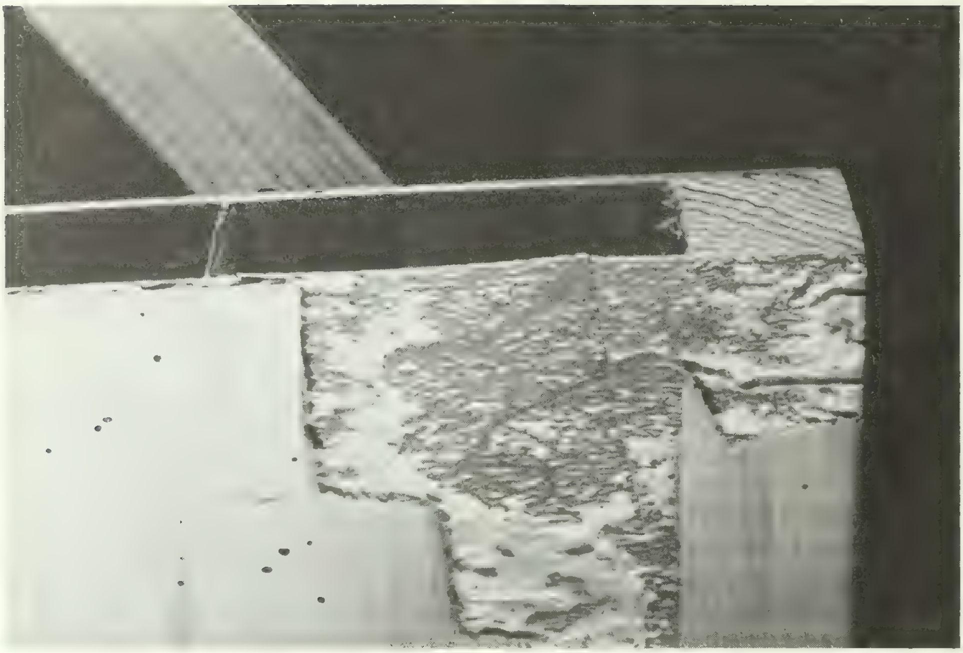

Figure 2.—*A three-ply parana pine door panel imported from Brazil with extensive damage by* L. brunneus *beetles in the unidentified hardwood inner core.*

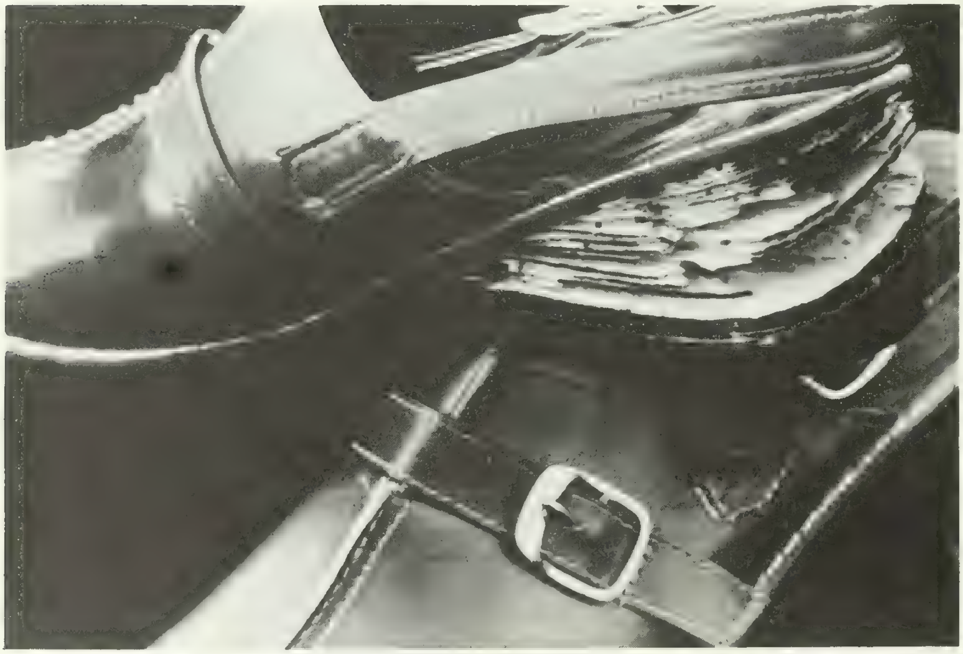

Figure 3.—*Shoes imported from Taiwan with extensive lyctid beetle damage in the wooden heel.*

finished, air-dried wood is sometimes stored for 6 months or more during transporting, processing, and marketing.

Quarantine inspections of hardwood imports at ports-of-entry do not necessarily insure that lyctid infestations will be detected and treated. Infestations of eggs and small larvae are not likely to be detected because no external damage shows. Also, because most tropical hardwood imports are semimanufactured and containerized, inspection is often limited to external surfaces of packaged lumber and bundles containing 200 veneer sheets or furniture squares. Most importantly, the main purpose of quarantine is to prevent entry of exotic pests, not to limit the distribution of pests already established or their damage. For example, though *Lyctus brunneus* (Stephens) is the species most frequently infesting tropical hardwood imports according to Bletchly (1960), Cymorek (1977), and my own records, infestations detected at ports are not treated by quarantine because this beetle is established in the United States.

Outlook for Prevention and Control

Because tropical hardwood imports may double by the year 2000 (USDA 1976), lyctid infestations, damage, and remedial control problems will increase unless quarantine requirements change for imports of hardwoods or unless hardwood importers and manufacturers use preventive treatments on raw imports and manufactured products. To prevent attack of domestic hardwoods and spreading of infestations when domestic and imported woods are stored together, preventive treatments would have to be applied to all susceptible domestic and foreign woods. Although the incidence of infestations may not seem to warrant the additional expense, widely applied prevention is important because remedial controls often are limited to replacement of high-valued products or tent fumigation. And combined costs of performing such controls, wood loss, and litigation over damage liability are very expensive.

Insuring that preventive treatments are properly applied to tropical hardwoods in foreign countries or that all hardwoods are treated would be expensive (and perhaps impossible) so a system of prevention for individual firms needs to be developed. The system would combine sterilization of wood by kiln-drying or microwave heating with inexpensive chemical treatments giving permanent protection of products made from sterilized wood. Because prevention would not always be done, safe, inexpensive remedial controls also are needed for use within structures.

BOSTRICHIDAE

Conditions Influencing Infestations

Most wood-infesting bostrichids also attack recently processed hardwoods with high starch content, but their attacks are not restricted to wood with large pores. Most native bostrichids lay eggs in bark on wood with a moisture content above 30 percent. Most infestations occur while hardwoods are being air-dried, and many are found in firewood. A few native species infest coniferous woods and their larvae occasionally survive in air-dried structural timbers. An exception is the leadcable borer (*Scobicia declivis* [LeConte]); females bore short tunnels for egg laying and infestations occur in lead sheathing of cables and dry wood such as wine casks (Ebeling and Rierson 1973, Fisher 1950). Tropical species within the genera *Heterobostrychus* and *Sinoxylon* also lay eggs in short tunnels bored into bare wood and are very destructive to recently processed hardwoods, particularly unseasoned crates and pallets (Bletchly 1967). Once the wood dries, however, reinfestation is rare.

Changes Influencing Infestations

The likelihood of native bostrichids damaging domestic hardwood products has been minimized by improved processing and transportation technology. Of all wood-infesting insects, however, bostrichids are most frequently intercepted by U.S. quarantine officials (Williams and La Fage 1979). The most commonly occurring species are *Heterobostrychus aequalis* (Waterhouse), *Sinoxylon anale* Lesne, and *S. conigerum* Gerstaker. Many infestations are in crating, pallets, and dunnage which are included with all types of import cargo. Because the volume of such cargo has increased greatly, some undetected bostrichid infestations are surely entering the country.

Outlook for Prevention and Control

The greatest danger may be introduction of a tropical species that can attack native hardwood trees, especially weakened ones. At least two species, *Dinoderus minutus* Fabricius (Baker 1972) and *H. aequalis*, are established in the south (USDA 1967, Woodruff 1967). Since its discovery in 1967 at Fort Lauderdale, Florida, *H. aequalis* seems to be spreading rapidly. Specimens have been collected from throughout Florida, Georgia, and northward to North Carolina.[5]

Preventive measures taken for lyctid beetles would also prevent bostrichid infestations in manufactured products, but prevention of bostrichids entering with general cargo will depend on quarantine procedures.

CERAMBYCIDAE

Conditions Influencing Infestations

The old house borer (*Hylotrupes bajulus* L.) is the major cerambycid pest of seasoned wood. Although the old house borer was introduced into the United States before 1841 (St. George et al. 1957), its distribution remains largely confined to the Atlantic Coast States from Florida to Massachusetts. Temperature apparently is a limiting factor because adult flight is rare below 25°C and 30°C is optimum (Cymorek 1968). Other cerambycids occasionally occur in ash, pecan, and other recently seasoned furniture stock. *Arhopalus* spp. occasionally infest air-dried western conifer lumber. Of these minor pests, only *Smodicum cucujiforme* (Say) infests dry wood.

The old house borer mainly attacks southern pine, spruce, and Douglas-fir—woods usually used for structural frameworks. A high nitrogen level in wood favors infestations and old house borers prefer to attack freshly processed wood. Infestations are often introduced into structures when infested materials are used in construction.

Attacks in existing structures are influenced by the same factors that affect the Anobiidae. Because optimal temperatures (28-30°C) for old house borer mating, egg hatching, and feeding are higher than for anobiids and the minimum wood moisture requirement is lower (Becker 1942, Berry 1972, Durr 1956), severe infestations can occur in attics, especially when shade lowers the temperature and lack of adequate ventilation increases moisture.

Although this large beetle is potentially very damaging, damage is usually slight in an occupied house where central systems control temperature and humidity, if no other moisture problems exist (Moore 1978a). But initial infestations such as in exposed ceiling beams can cause extensive damage. Therefore, the public often desires the immediate control given by fumigation even though the structural damage likely to occur does not warrant the expense (Moore 1978b).

Changes Influencing Infestations

Fewer crawl spaces are being built, and many roof trusses are being prefabricated with wood treated with temporary water repellents. Such prefabrication minimizes the time that kiln-dried wood is exposed to egg-laying females during construction. So the number of infestations should decline, though the present increase in the inspection of attics by pest control firms may suggest an opposite trend.

Most softwood lumber is currently kiln-dried, but higher energy costs may lead to more air-drying of wood and thereby increase the likelihood of infestations. Also, increased use of insulation in attics and crawl spaces will make discovery and treatment of infestations more difficult (Moore 1978c).

Outlook for Prevention and Control

Because the old house borer has not greatly extended its range westward in more than 150 years since its introduction, it seems unlikely that the number of infestations will greatly increase. More thorough inspections within its present range may suggest so however.

Expense of preventing old house borers, other than by using kiln-dried wood in construction, should not be warranted (Moore 1978a,c). Pretreatment of log-kit construction, however, is an exception and should be done. Also, safe, inexpensive remedial controls need to be developed so expense of fumigating limited infestations can be avoided.

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[5] Williams, Lonnie H. 1977. Personal correspondence with Dr. Phil Koehler, Extension Entomologist, Univ. Fla. (On file For. Sci. Lab., Gulfport, Miss.)

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Anobiid beetle infestations should decline because fewer houses are being built with crawl spaces and more houses have central heating and air-conditioning. Increased imports of tropical hardwoods may increase likelihood of lyctid infestations, and the incidence of attacks by old house borers should change little

Additional keywords: wood-destroying beetles, anobiid beetles, bostrichid beetles, lyctid beetles.

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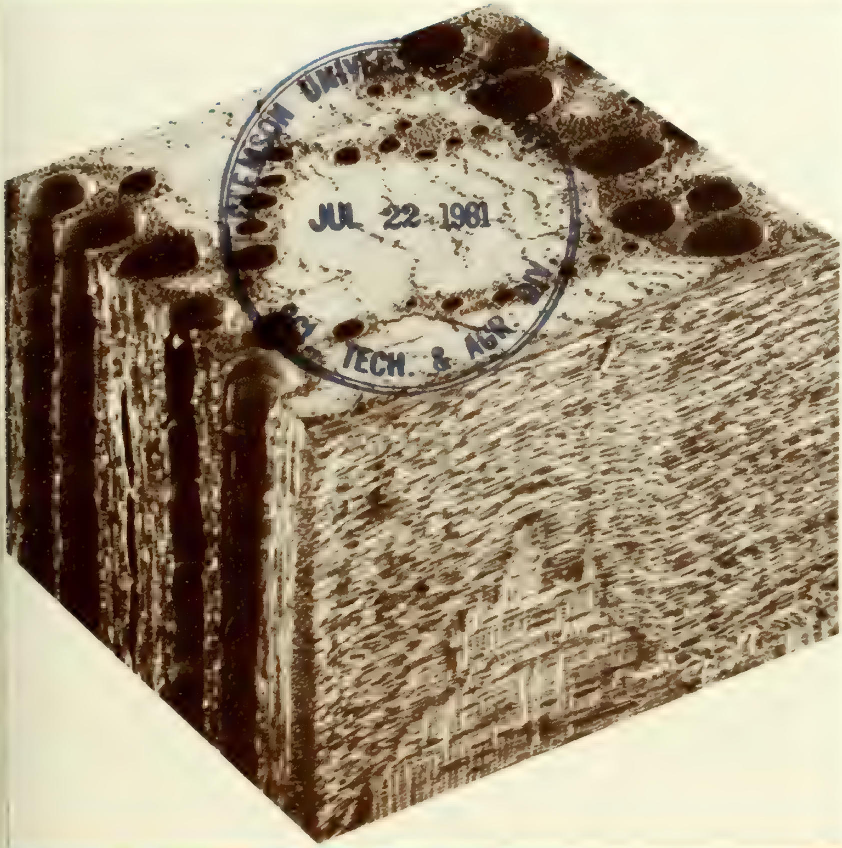
The Wood and Bark of Hardwoods Growing on Southern Pine Sites — A Pictorial Atlas

Charles W. McMillin
and Floyd G. Manwiller



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SUMMARY

A pictorial description of the structure and appearance of 23 hardwoods growing on pine sites is presented along with a brief overview of hardwood anatomy. Scanning electron microscopy is used to depict the radial, tangential, and transverse wood surfaces in a single three-dimensional presentation. Color photographs of the three surfaces and of the bark provide additional visual data useful in both product development and species identification. Data on the resource and certain important physical properties of the stemwood and bark are also tabulated for most species.

AFFILIATIONS

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Southern Forest Experiment Station

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The Wood and Bark of Hardwoods Growing on Southern Pine Sites – A Pictorial Atlas

Charles W. McMillin and Floyd G. Manwiller

INTRODUCTION

Hardwoods growing on southern pine sites[1] constitute a vast forest resource of about 49 billion cubic feet. Twenty-three species or species groups (table 1) comprise about 90 percent of the resource with 11 oaks alone accounting for 49.1 percent. Of the oaks, all are members of the red oak group except post oak, chestnut oak, and white oak, which are members of the white oak group. The entire resource is typically small in diameter, slow in growth, and low in quality. For these and other reasons, few existing processes can economically convert significant volumes to useful forest products.

Yet, most economists agree that to meet future needs southern forests must yield substantially more wood than they do now. Research underway at the Southern Forest Experiment Station and elsewhere is developing new processes that will use these neglected pine-site hardwoods and thus greatly extend the nation's timber supply.

The purpose of this paper is to provide a pictorial description of the wood and bark of the pine-site hardwood resource. A scanning electron microscopy technique (Manwiller 1975a, McMillin 1977) was used to depict the anatomy of the radial, tangential, and transverse wood surfaces in a single three-dimensional presentation. Color photographs of the three surfaces and of the bark provide additional visual data useful in both product development and species identification. Data on the resource and certain important physical properties of the stemwood and bark are also tabulated for most of the 23 species.

An overview of hardwood structure is provided as introductory reading. Detailed discussions of wood anatomy and characterization of individual species may be found in more comprehensive texts (Panshin and de Zeeuw 1970; Core, Côté, and Day 1979). Readers interested in an illustrative monograph of the living tree should also find Southern Forest Experiment Station, General Technical Report SO-15, "Identifying Hardwoods Growing on Pine Sites" a useful source (Brown and Grelen 1977).

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[1] For purposes of this paper, pine sites are defined as forested uplands, excluding those growing cove-type hardwoods, capable of growing southern pine as demonstrated by present or former occurrence on the site.

Table 1. – *The hardwood resource on southern pine sites, ranked according to percentage of total hardwood volume*

Common name	Botanical name	Percent[1]
Sweetgum	*Liquidambar styraciflua* L.	13.2
White oak	*Quercus alba* L.	12.3
Hickory	*Carya* spp.	8.5
Southern red oak	*Quercus falcata* Michx. var. *falcata*	8.1
Post oak	*Quercus stellata* Wangenh.	7.0
Yellow-poplar	*Liriodendron tulipifera* L.	7.0
Black tupelo	*Nyssa sylvatica* Marsh.	5.5
Water oak	*Quercus nigra* L.	4.7
Chestnut oak	*Quercus prinus* L.	4.2
Black oak	*Quercus velutina* Lam.	4.0
Scarlet oak	*Quercus coccinea* Muenchh.	3.6
Red maple	*Acer rubrum* L.	3.6
Northern red oak	*Quercus rubra* L.	2.4
Laurel oak	*Quercus laurifolia* Michx.	1.4
American elm	*Ulmus americana* L.	1.4
Winged elm	*Ulmus alata* Michx.	
Cherrybark oak	*Quercus falcata* Michx. var. *pagodaefolia* Ell.	1.2
Green ash	*Fraxinus pennsylvanica* Marsh.	.9
White Ash	*Fraxinus americana* L.	
Sweetbay	*Magnolia virginiana* L.	.6
Shumard oak	*Quercus shumardii* Buckl.	.2
Hackberry	*Celtis* spp.	.1
Other hardwoods including Blackjack oak	(*Quercus marilandica* Muenchh.)	10.1
TOTAL		100.0

[1] Percentages were derived from Staff, For. Resour. Res. Work Unit (1976).

OVERVIEW OF HARDWOOD STRUCTURE

How the cellular structure of wood is organized can best be understood from study of three surfaces – transverse, tangential, and radial. Figure 1-A shows a portion of a hardwood stem with an enlarged bark-to-pith, wedge-shaped section removed. The wedge (1B) locates the three study surfaces and illustrates their orientation within the stem.

Between the wood (xylem) and the bark, a sheath of tissue called the cambium repeatedly produces new layers of wood and inner bark. These layers increase stem diameter. Some cells (parenchyma) of the newly formed xylem perform living functions, but most die during the year they are formed. These dead cells have a rigid cell wall and a cavity, called a lumen, where the living protoplasm was during cell formation.

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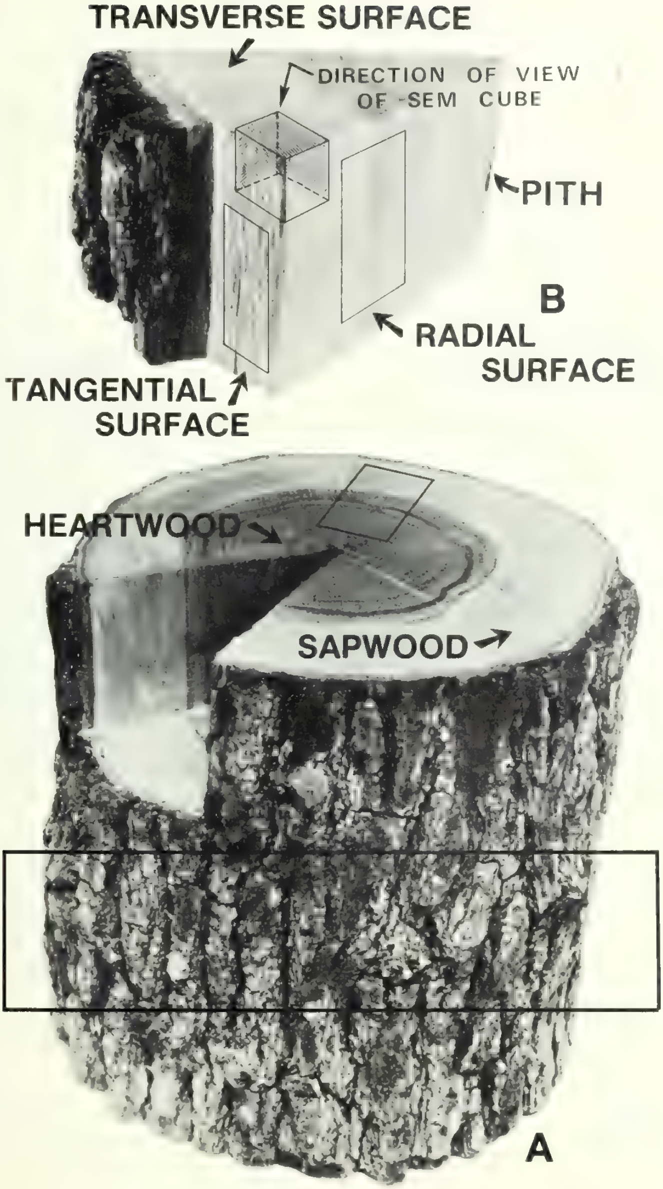

Fig. 1 – *Photograph showing orientation of study surfaces within a hardwood stem.*

That portion of xylem containing some living cells (parenchyma) is termed sapwood (fig. 1-A). The transformation from sapwood to heartwood occurs when all physiological functions of the sapwood xylem cease. At that time, food reserves stored in parenchyma cells are converted to extractives which make the heartwood of many species darker than their sapwood.

Heartwood may resist insect and fungal attack better than sapwood. But, the presence of extractives and certain anatomical structures (i.e., tyloses) may make heartwood less permeable than sapwood and impair preservation, drying, and pulping processes.

The scanning electron microscope, because of its great depth of field, enables one to observe all three study surfaces simultaneously in their proper spatial relationship and at sufficient magnification to see certain important anatomical features. Figure 2 shows a scanning electron micrograph of Shumard oak. The surfaces depicted in figure 2 are viewed from the direction of the pith (as indicated by the arrow in figure 1-B). The study surfaces are further identified by the hatched lines on the cube in figure 1-B.

Broad-leaved, deciduous hardwoods are anatomically more complex (as are all hardwoods) than coniferous softwoods because they are composed of more cell types. Several structures readily distinguish the two groups. Notably, hardwoods have vessels (fig. 2) – structures that conduct water within the stem. Also, the radial alignment of cells characteristic of softwoods is lacking or obscured in hardwoods. Lastly, hardwood rays are more variable in width and height than those of softwoods. Hardwood rays are frequently two or more cells wide and may be as wide as 30 or more cells in oaks.

The terms "hardwoods" and "softwoods" do not necessarily reflect the hardness of the wood. For example, yellow-poplar, a "hardwood," is softer and more easily indented than Pacific yew, a "softwood."

In figure 2, the transverse surface shows portions of two annual growth increments consisting of both earlywood and latewood. Earlywood is that portion of the annual ring produced in the spring, and latewood is formed towards the end of the growing season. The major anatomical elements and structures identified in figure 2 are discussed in subsequent text. The reader is also directed to micrographs of other species in the section on "Species Illustrations, Resource, and Selected Properties."

Fibers

Fibers (slender, elongated cells with pointed, closed ends) are oriented vertically in the stem, parallel to its long axis. Because of their thick walls and small-diameter lumens, fibers appear at low magnification to

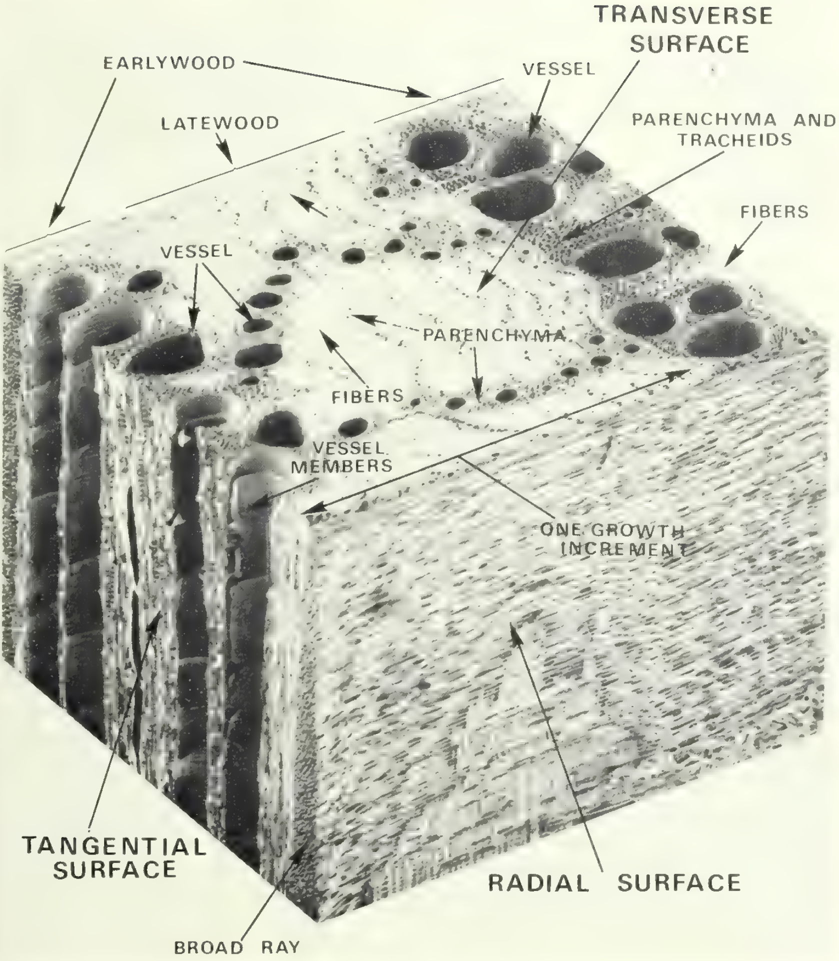

Fig. 2—*Scanning electron micrograph of Shumard oak cube.*

be background tissue to other cell types in both earlywood and latewood (transverse surface of fig. 2). Several different fiber types exist but are difficult to categorize, so separation is not attempted in this paper.

Fibers support the stem and are the most numerous anatomical element, comprising about 45 percent of the stemwood volume of the species surveyed. Average lengths vary from 0.8 mm in red maple to 1.8 mm in black tupelo (Manwiller 1974).

From the standpoint of hardwood utilization, fibers give strength to solid wood products and are the principal component of paper and other products derived from pulp.

Vessels

Vessels are structures of indeterminant length and are composed of a series of short cells, the vessel members (elements), whose end walls have partially disappeared, forming a vertical tube. Vessel openings in both earlywood and latewood are clearly visible on the transverse surface of figure 2, and vessel members may be seen on the tangential surface where vessels have been cut. For the species considered here, vessels comprise about 20 percent of the cell volume although values range from 11.2 percent for cherrybark oak to 46.2 percent for sweetgum.

The partial end wall remaining between two adjacent vessel members is a perforation plate, and the opening is a perforation. In most species considered here (the ashes, elms, hackberry, hickory, red maple, and oak), vessel members are joined by simple perforation plates—large round openings with only a narrow rim remaining from the original wall. Vessel members and simple perforation plates are easily seen on the radial surface of the green ash cube (p. 12).

In sweetbay, sweetgum, black tupelo, and yellow-poplar, vessel members are joined through scalariform (ladderlike) perforation plates where barlike remnants of the end wall separate long, slender, parallel perforations. This type of perforation plate is most clearly visible in cut vessels on the radial surface of sweetgum (p. 52).

Vessels are also called pores. If vessels are all of about the same diameter across the growth increment (as in red maple, sweetbay, sweetgum, black tupelo, and yellow-poplar) the species is said to be diffuse-porous. In the other species (the ashes, elms, hackberry, true hickory, and the oaks), the vessels in the earlywood are much larger than those in the latewood, and the change in diameter is abrupt. These species are termed ring-porous.

When the latewood tissue is wide enough for the pattern to be visible, the arrangement of latewood vessels in ring-porous wood varies considerably among species. The slow-grown hickory cube (p. 22) has solitary pores although other hickory samples may have pores in radial groups of two or three. In the ashes, latewood pores are also both solitary and in radial groups of two and three. Elms and hackberry have wavy, nearly continuous tangential bands of latewood vessels, while oaks have latewood vessels generally aligned in the radial direction. In the red oaks, latewood vessels occur as rows one cell wide or in flame-shaped groups and are easily seen because of their thick walls. White oaks have smaller, thin-walled latewood vessels, which occur in flame-shaped groups — an arrangement clearly visible on the transverse surface of post oak (p. 38).

The relative amounts of latewood and earlywood can affect important physical properties of ring-porous hardwoods. For example, the slow-grown northern red oak cube (p. 36) is essentially composed of four narrow rings, primarily earlywood tissue. This sample is much more porous and has a lower density than the fast-grown Shumard oak cube (p. 42), which is composed of virtually one wide growth ring containing much fibrous latewood.

Parenchyma

Longitudinal parenchyma cells have about the same diameter as fibers but are shorter and have thinner walls. The vertically oriented longitudinal parenchyma may be seen on the transverse surface of figure 2 as short series of cells interspersed among fibers. Parenchyma is also oriented horizontally in rays. Longitudinal stemwood parenchyma volume ranges from less than 2 percent in sweetgum to about 26 percent in the oaks.

Longitudinal parenchyma is sparse in diffuse-porous species such as red maple, sweetgum, and black tupelo. In sweetbay and yellow-poplar it forms a continuous band at the end of seasonal growth and appears as a white line at low magnification. Parenchyma is more apparent in the ring-porous species. Lumen diameter of parenchyma cells is larger than that of fibers but less than that of latewood vessels. In the ashes, parenchyma occurs in the latewood, where it encircles individual and multiple vessels and often extends outward from them in tangential rows. Parenchyma is present in the oaks as fine tangential lines throughout the latewood — also, most of the flame-shaped tissue surrounding latewood vessels is composed of parenchyma. In hickories, parenchyma is conspicuous as tangential lines throughout the latewood.

Tracheids

The small, large-lumened cells surrounding earlywood vessels in the oaks appear to be parenchyma on the transverse surface. They are, however, primarily vasicentric tracheids, which are longer and thicker walled than parenchyma cells and are not in longitudinal rows. They also appear among the flame-shaped areas of parenchyma.

Another type of tracheid, vascular, is found in the elms and hackberry. Vascular tracheids are similar to latewood vessel members except that end walls are not perforated. They may be intermixed in the same vertical series with the vessel members, are associated with vessel members in the wavy latewood bands, and cannot be distinguished from them on the transverse surface.

Rays

On the transverse surface, rays (fig. 2) appear as lines extending across growth increments from the cambium toward the pith. On the radial surface they appear as ribbons while the ends of rays are exposed on the tangential surface. Composed of horizontally-oriented parenchyma, rays are from several to many cells high and are generally tapered on their upper and lower edges. (See for example the tangential surface of the sweetbay cube on page 50.)

Rays vary from one to several cells wide. Of the species considered here, only the oaks contain broad rays—up to 30 cells wide and hundreds of cells high. Between these broad rays are many inconspicuous rays, usually one cell wide and less than 20 cells high. In all of the oak cubes except that of black oak the radial surface cuts through a broad ray.

Of the remaining 11 species, the rays of the two elms and hackberry are usually five or six cells wide, while those of the other eight species are mostly one to three cells wide.

Tyloses

Between any two adjacent cells, regardless of type, there are minute matching gaps in the contiguous walls of the two cells. The gaps are separated at the center by a membrane. The cavities in adjacent walls plus membranes are called pits. Tyloses are outgrowths of protoplasm from longitudinal or mainly ray parenchyma cells that expand or grow through the pit membranes and appear as membranelike material that partially or completely blocks the vessel cavity.

Tyloses block most of the earlywood vessels of the white oak group. Tyloses occur only occasionally in the red oaks—some may be seen in vessels of laurel oak (p. 34) and blackjack oak (p. 28). Tyloses are also present in some earlywood vessels of the hickory cube (p. 22).

SPECIES ILLUSTRATIONS

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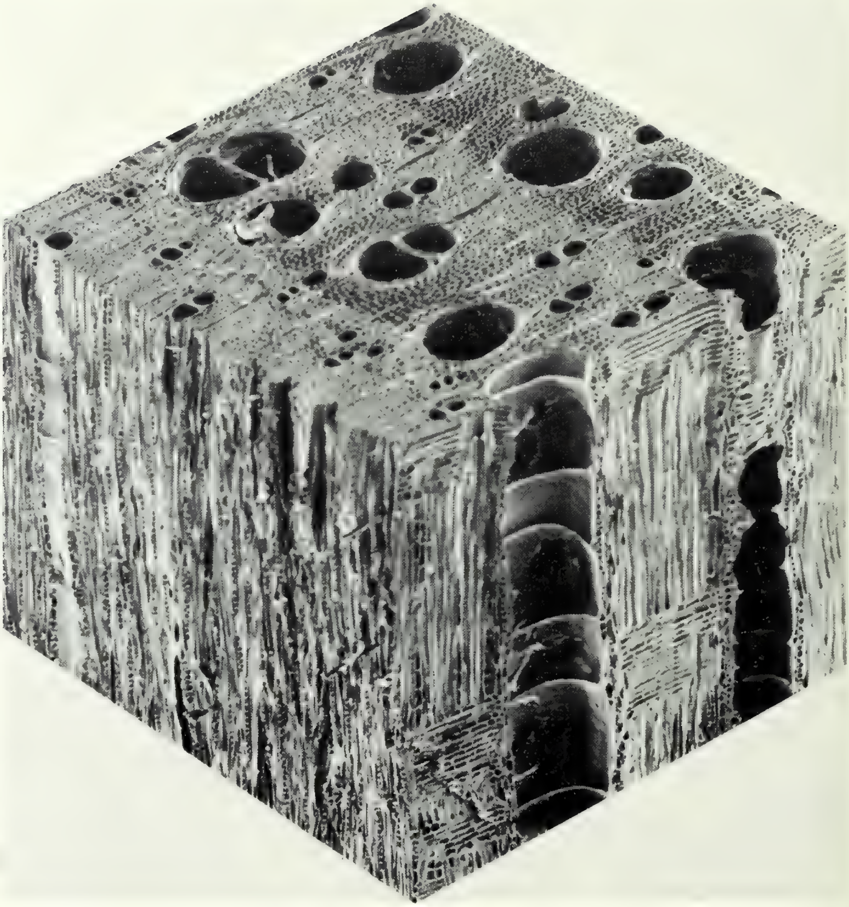
SPECIES ILLUSTRATIONS, RESOURCE, AND SELECTED PROPERTIES

Each species is illustrated by five pictures: a scanning electron micrograph magnified 100 times so one can see the cellular structure in perspective; a photograph of the transverse surface magnified five times (the surface and minimum magnification useful for species identification); unmagnified radial and tangential views that illustrate color and grain; and finally a picture of the bark, field-photographed from typical 6-inch (breast height) diameter trees. The location and orientation of each view in the tree is illustrated by the rectangles and the cube in figure 1.

The species resource and selected stemwood and bark properties are listed in the lower part of the right-hand page. These data were obtained from the following sources.

RESOURCE	
Volume (million cubic feet)	(Staff, For. Resour. Res. Work Unit, 1976)
Percent of hardwood volume on pine sites	(Derived from above)
STEMWOOD	
Specific gravity (ovendry weight and green volume)	(Manwiller, 1979)
Weight of bark-free stemwood when green (lbs/ft^3)	(Manwiller, 1975b)
Percent moisture content of green wood (ovendry basis)	(Manwiller, 1975b)
BARK	
Specific gravity (ovendry weight and green volume)	(Manwiller, 1979)
Percent moisture content of green bark (ovendry basis)	(Manwiller, 1975b)

The resource estimates tabulated are for the species or species group growing on pine sites only and do not reflect the additional hardwood volume growing on cove hardwood sites. The survey data are from 12 southern states—Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. Volumes are expressed in cubic feet, inside bark, of trees from stump to minimum 4-inch top diameter (outside bark) of the central stem. All trees 5 inches in diameter at breast height and larger are included.



Mag. × 100

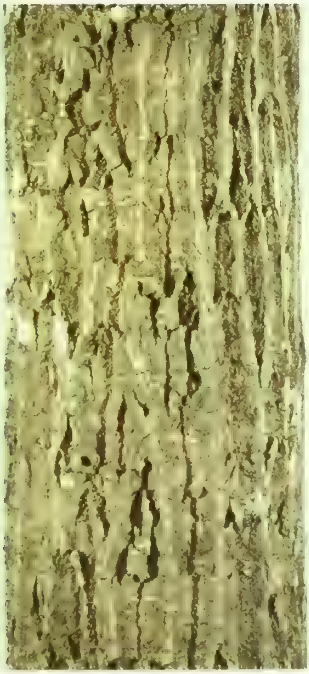
GREEN ASH

Fraxinus pennsylvanica Marsh.

Radial
Mag. ×1

Tangential
Mag. ×1

Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE
(With White Ash)

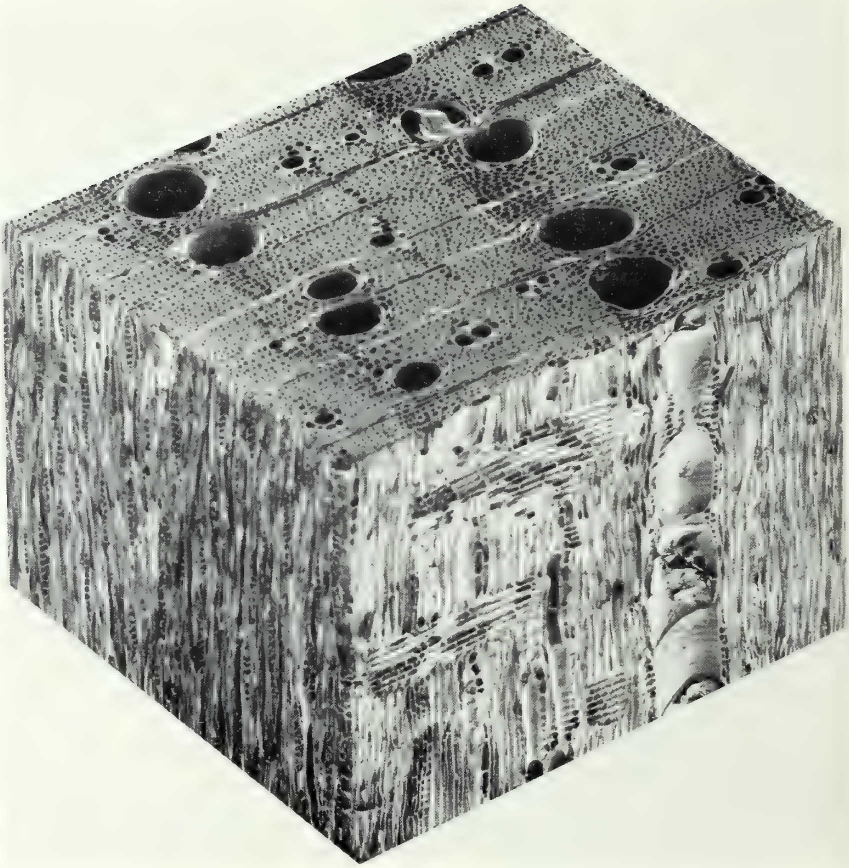
Volume *(million cubic feet)*	441
Percent of total hardwood volume on southern pine sites	0.9

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.561
Weight of bark-free stemwood when green *(lbs/ft^3)*	51.6
Percent moisture content of green wood *(ovendry basis)*	47.4

BARK

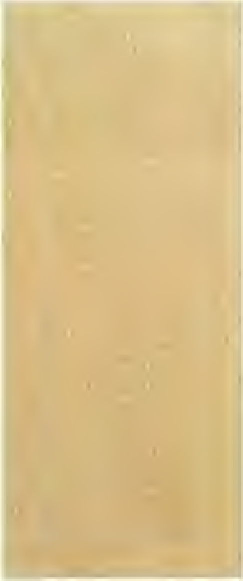
Specific gravity *(ovendry weight and green volume)*	0.407
Percent moisture content of green bark *(ovendry basis)*	75.9



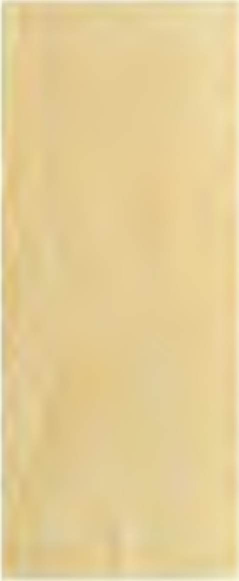
Mag. × 100

WHITE ASH

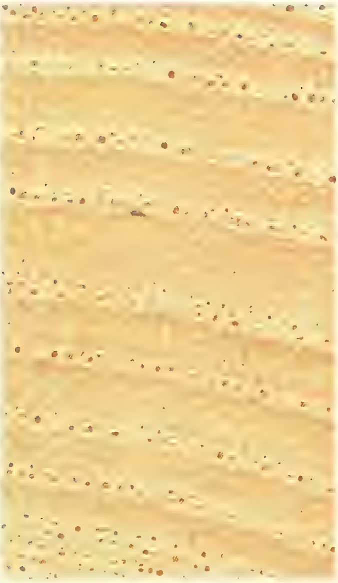
Fraxinus americana L.



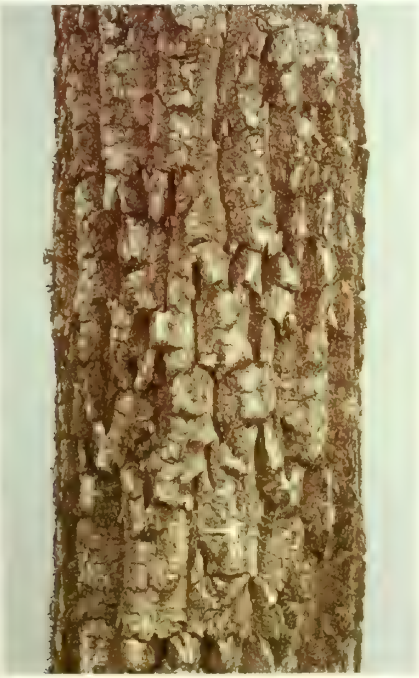
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

(With Green Ash)

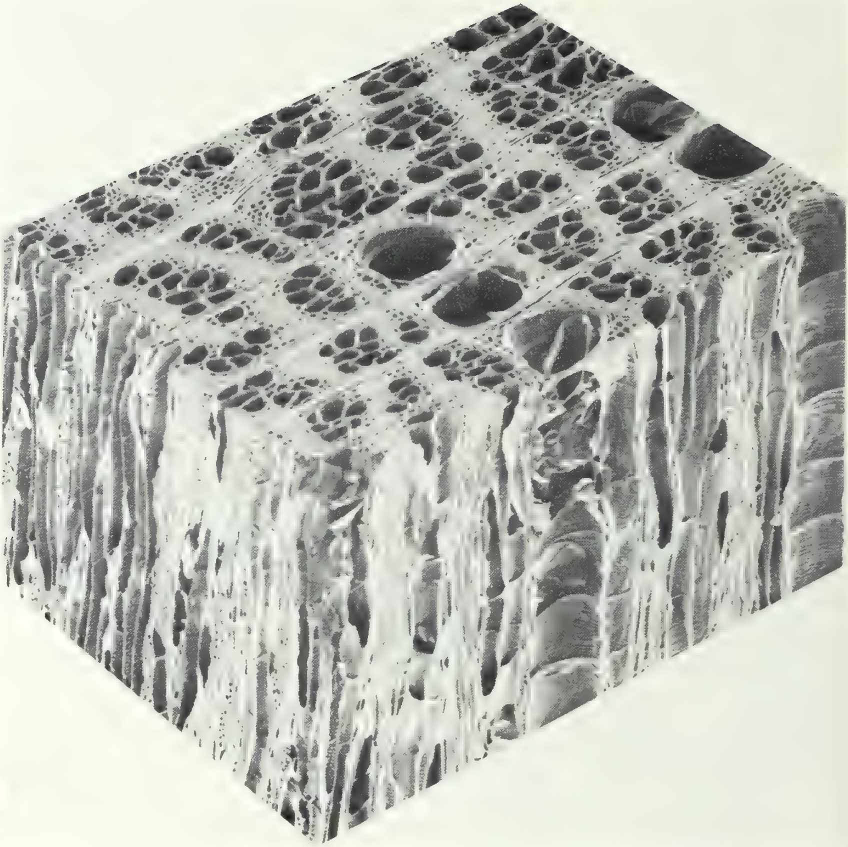
Volume *(million cubic feet)*	441
Percent of total hardwood volume on southern pine sites	0.9

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.582
Weight of bark-free stemwood when green *(lbs/ft^3)*	53.6
Percent moisture content of green wood *(ovendry basis)*	47.5

BARK

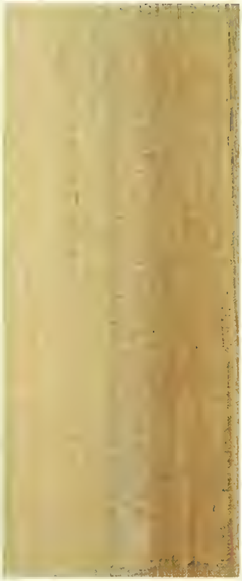
Specific gravity *(ovendry weight and green volume)*	0.397
Percent moisture content of green bark *(ovendry basis)*	68.4



Mag. × 100

AMERICAN ELM

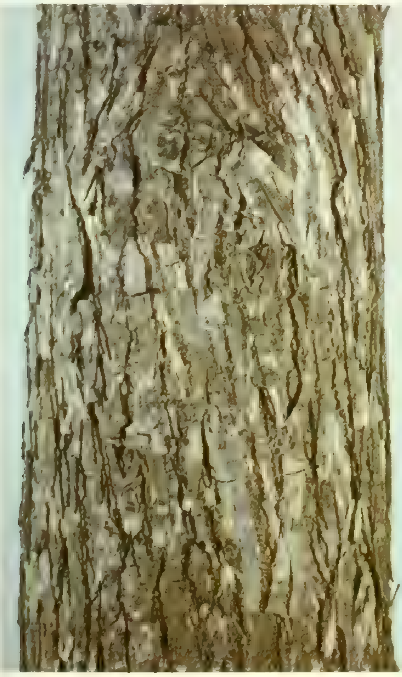
Ulmus americana L.



Radial
Mag. ×1

Tangential
Mag. ×1

Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE
(With Winged Elm)

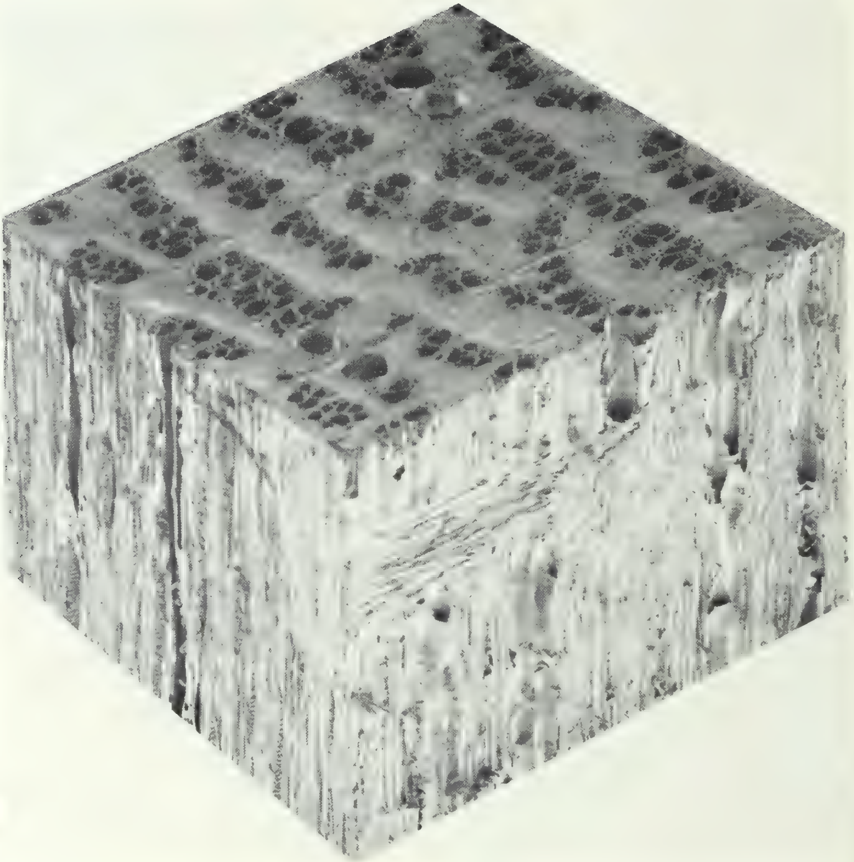
Volume *(million cubic feet)*	668
Percent of total hardwood volume on southern pine sites	1.4

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.536
Weight of bark-free stemwood when green *(lbs/ft^3)*	58.7
Percent moisture content of green wood *(ovendry basis)*	75.5

BARK

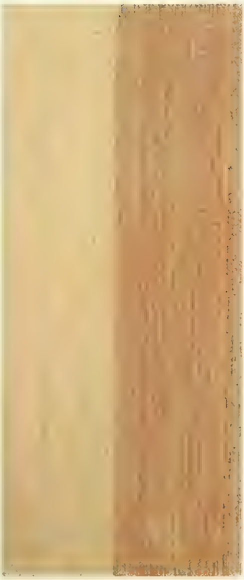
Specific gravity *(ovendry weight and green volume)*	0.395
Percent moisture content of green bark *(ovendry basis)*	86.9



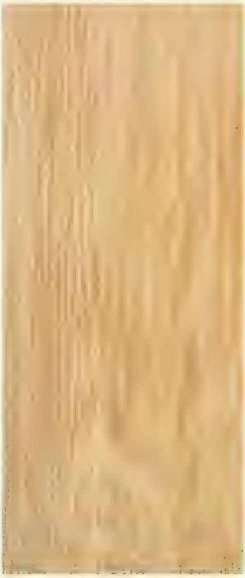
Mag. × 100

WINGED ELM

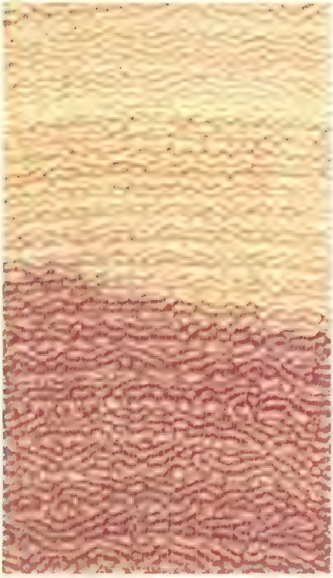
Ulmus alata Michx.



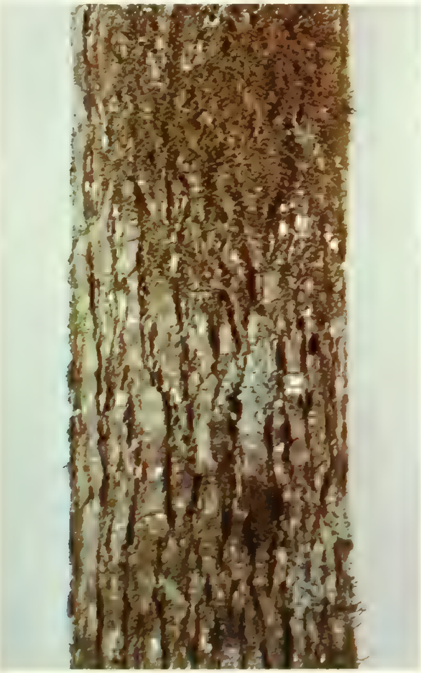
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

(With American Elm)

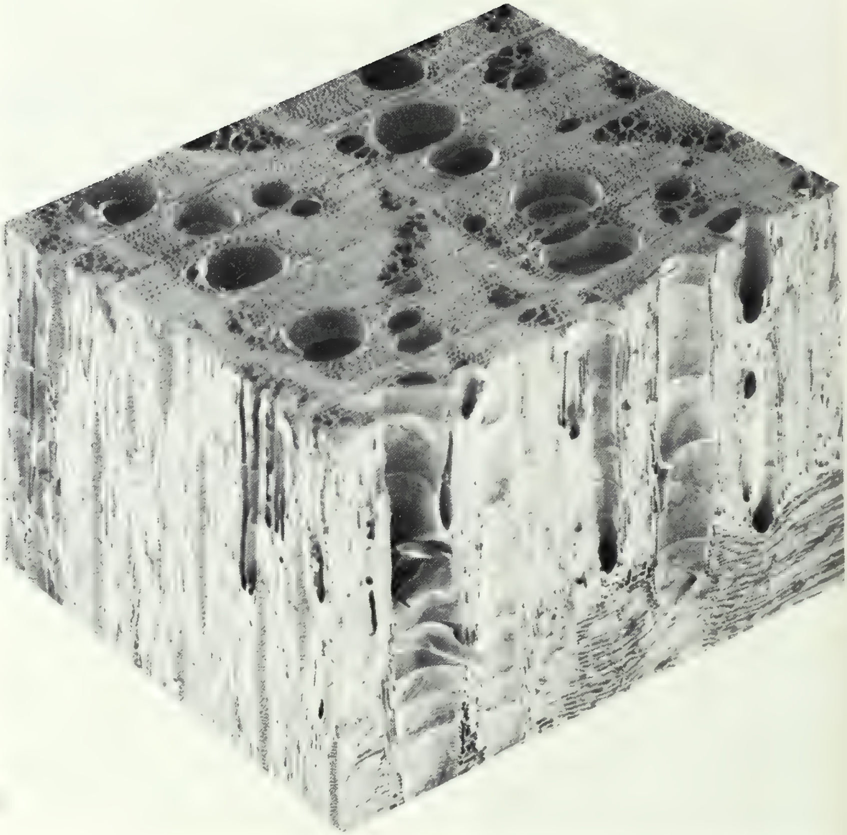
Volume *(million cubic feet)*	668
Percent of total hardwood volume on southern pine sites	1.4

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.623
Weight of bark-free stemwood when green *(lbs/ft^3)*	64.4
Percent moisture content of green wood *(ovendry basis)*	65.6

BARK

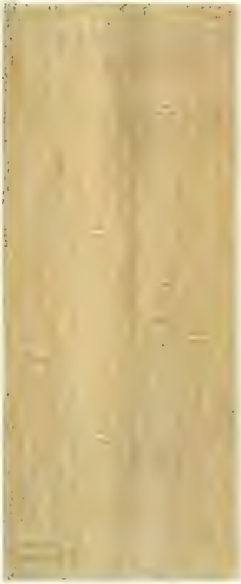
Specific gravity *(ovendry weight and green volume)*	0.341
Percent moisture content of green bark *(ovendry basis)*	76.0



Mag. × 100

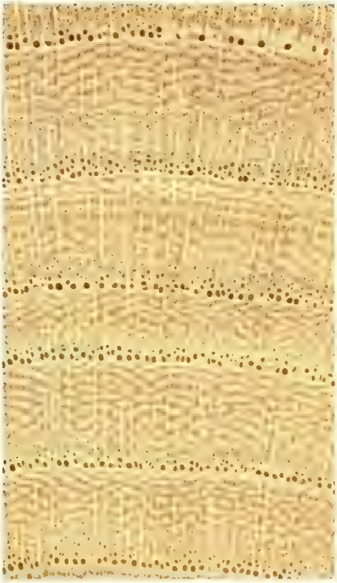
HACKBERRY

Celtis spp.

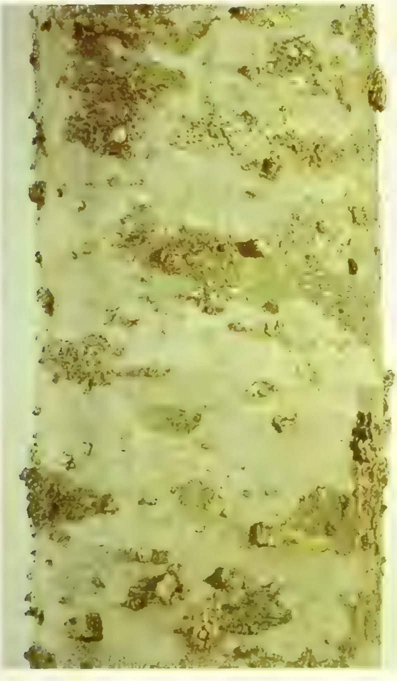


Radial
Mag. ×1

Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

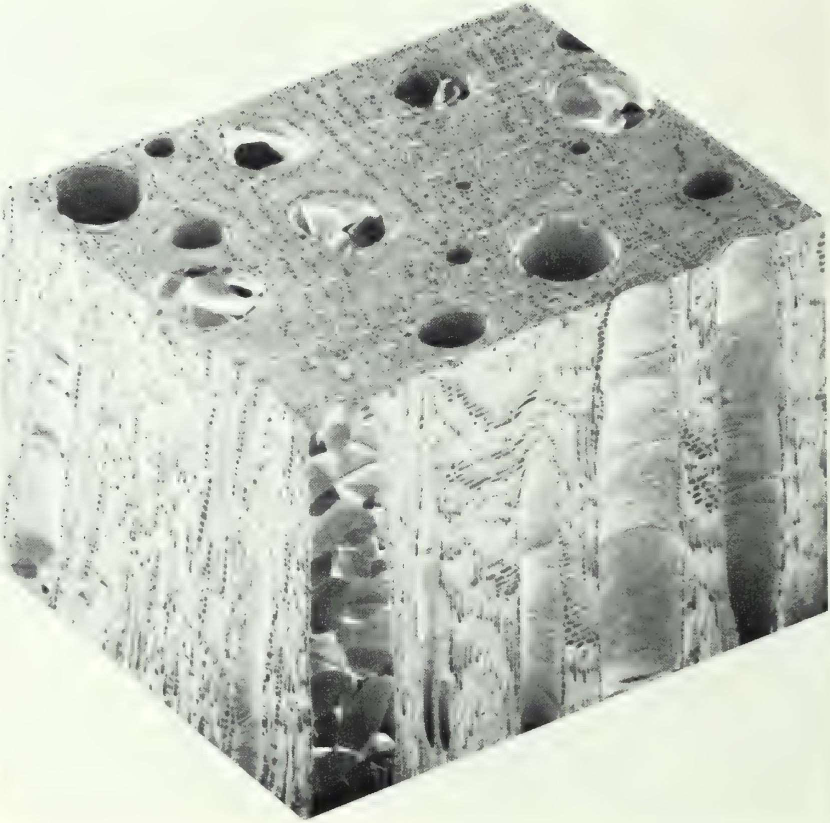
Volume *(million cubic feet)*	57
Percent of total hardwood volume on southern pine sites	0.1

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.525
Weight of bark-free stemwood when green *(lbs/ft³)*	56.6
Percent moisture content of green wood *(ovendry basis)*	72.6

BARK

Specific gravity *(ovendry weight and green volume)*	0.606
Percent moisture content of green bark *(ovendry basis)*	55.5

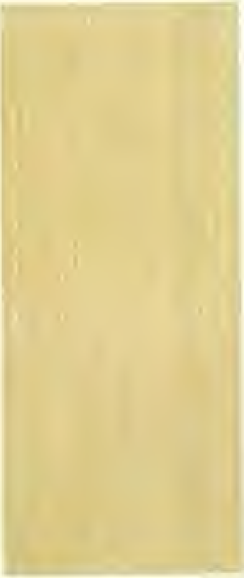


Mag. × 100

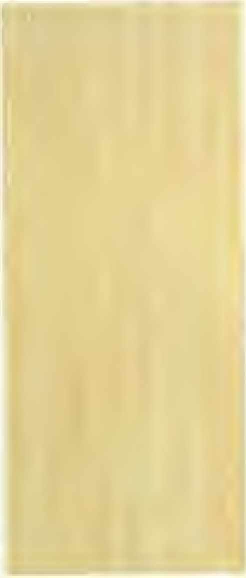
HICKORY

Carya spp.

Bark photograph is that of mockernut hickory (Carya tomentosa Nutt.)

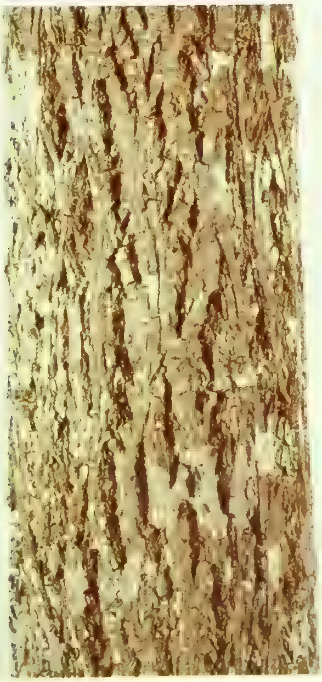


Radial
Mag. ×1



Tangential
Mag. ×1

Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

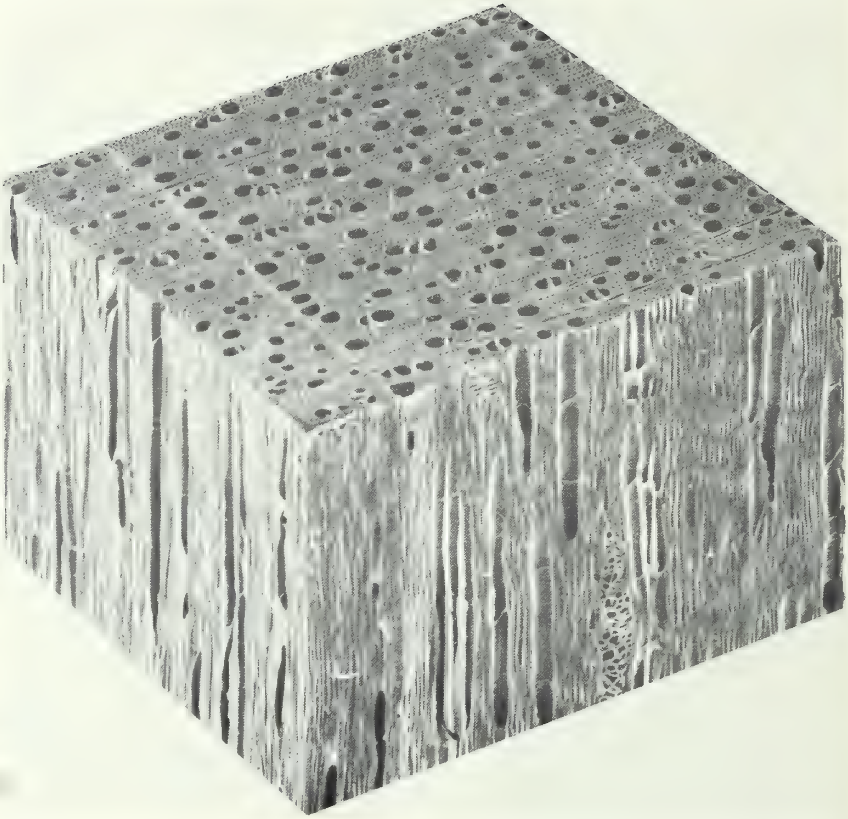
Volume *(million cubic feet)*	4173
Percent of total hardwood volume on southern pine sites	8.5

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.643
Weight of bark-free stemwood when green *(lbs/ft^3)*	60.8
Percent moisture content of green wood *(ovendry basis)*	51.5

BARK

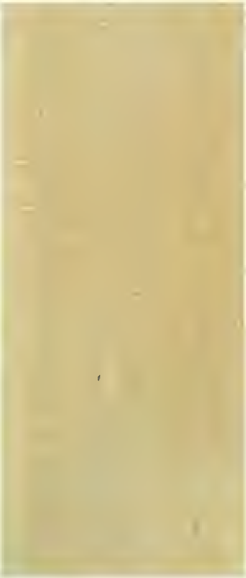
Specific gravity *(ovendry weight and green volume)*	0.522
Percent moisture content of green bark *(ovendry basis)*	72.9



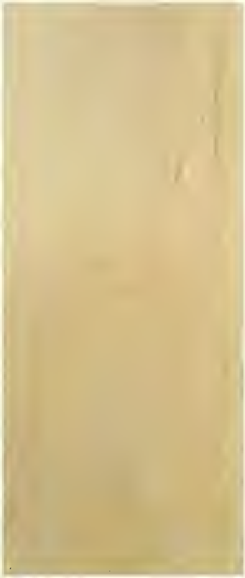
Mag. × 100

RED MAPLE

Acer rubrum L.

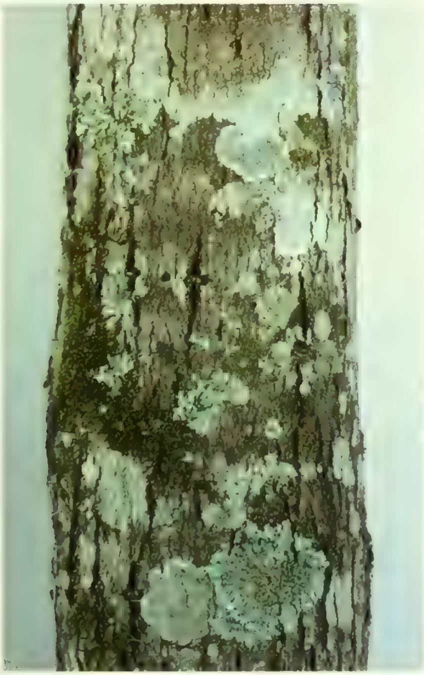


Radial
Mag. ×1



Tangential
Mag. ×1

Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

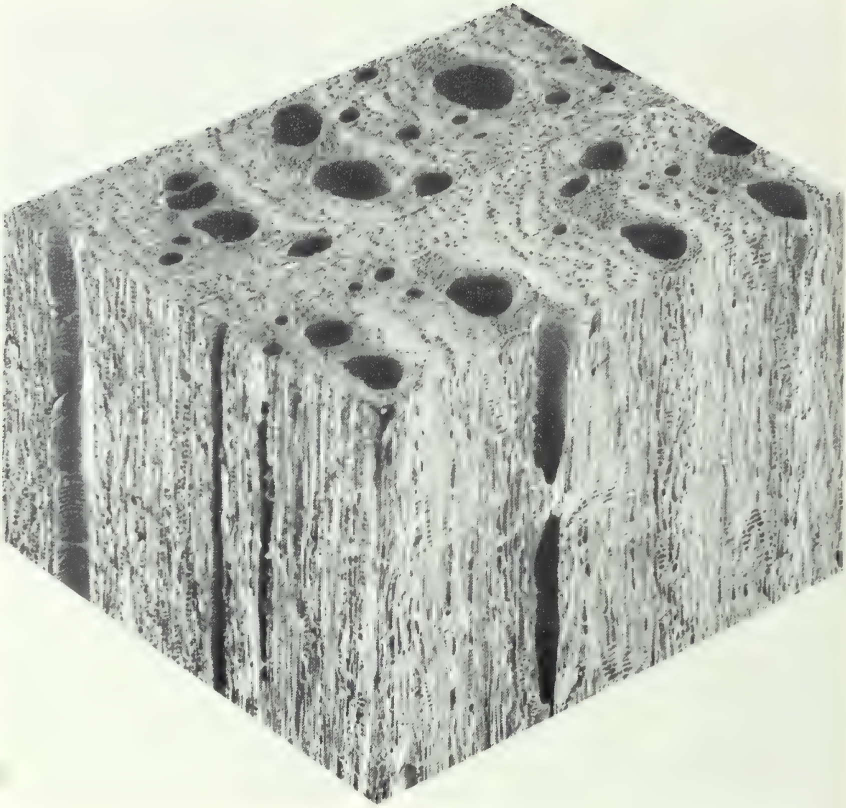
Volume *(million cubic feet)*	1751
Percent of total hardwood volume on southern pine sites	3.6

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.496
Weight of bark-free stemwood when green *(lbs/ft³)*	52.6
Percent moisture content of green wood *(ovendry basis)*	69.9

BARK

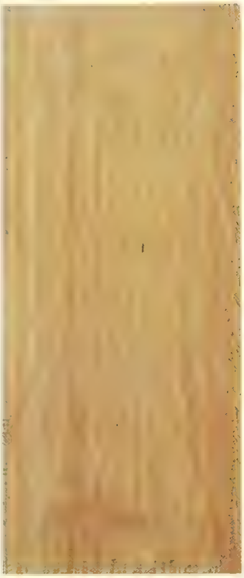
Specific gravity *(ovendry weight and green volume)*	0.535
Percent moisture content of green bark *(ovendry basis)*	74.4



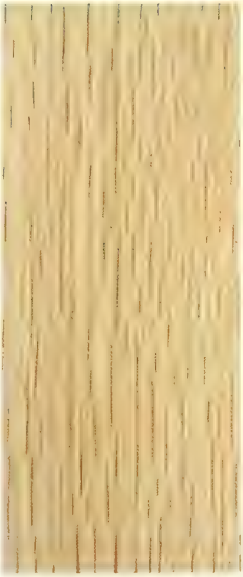
Mag. × 100

BLACK OAK

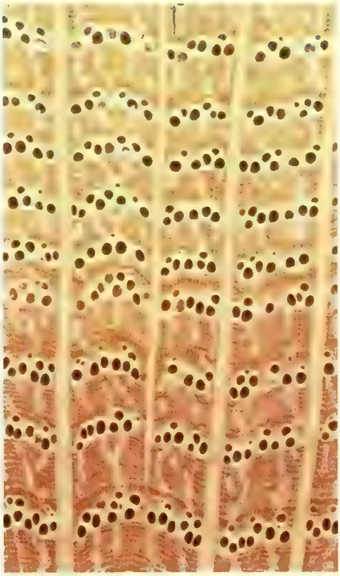
Quercus velutina Lam.



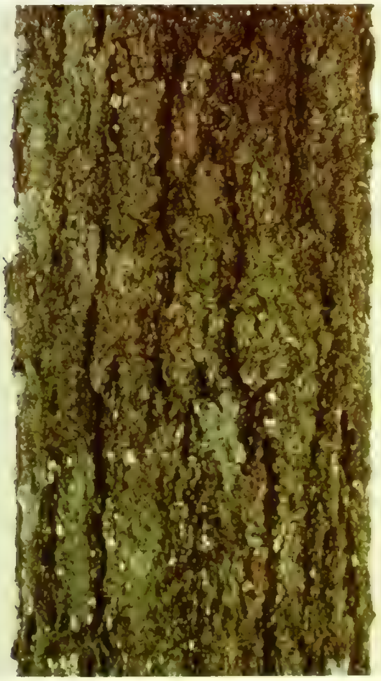
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

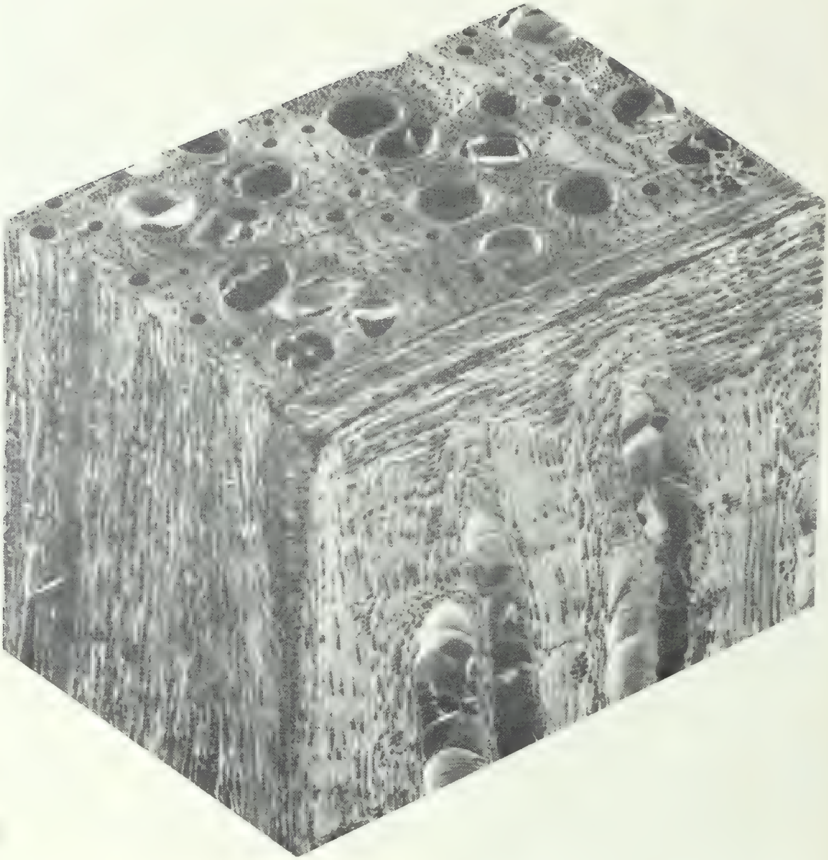
Volume *(million cubic feet)*	1949
Percent of total hardwood volume on southern pine sites	4.0

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.620
Weight of bark-free stemwood when green *(lbs/ft^3)*	65.5
Percent moisture content of green wood *(ovendry basis)*	69.2

BARK

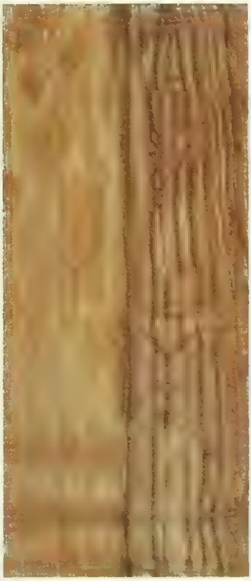
Specific gravity *(ovendry weight and green volume)*	0.612
Percent moisture content of green bark *(ovendry basis)*	56.2



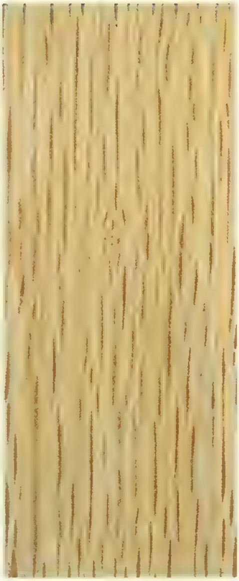
Mag. × 100

BLACKJACK OAK

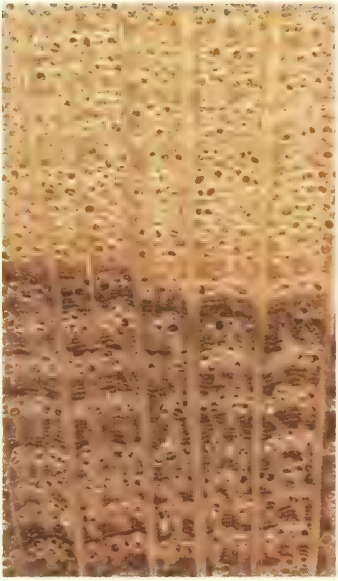
Quercus marilandica Muenchh.



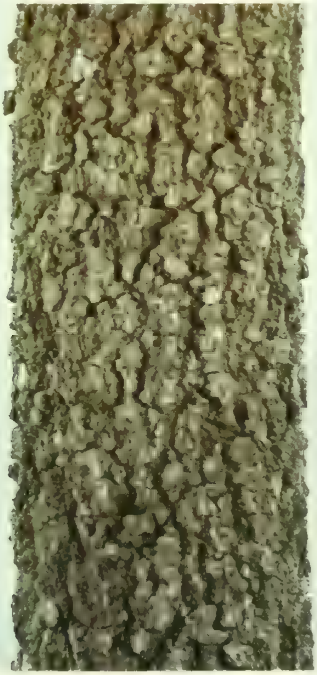
Radial
Mag. ×1



Tangential
Mag. ×1

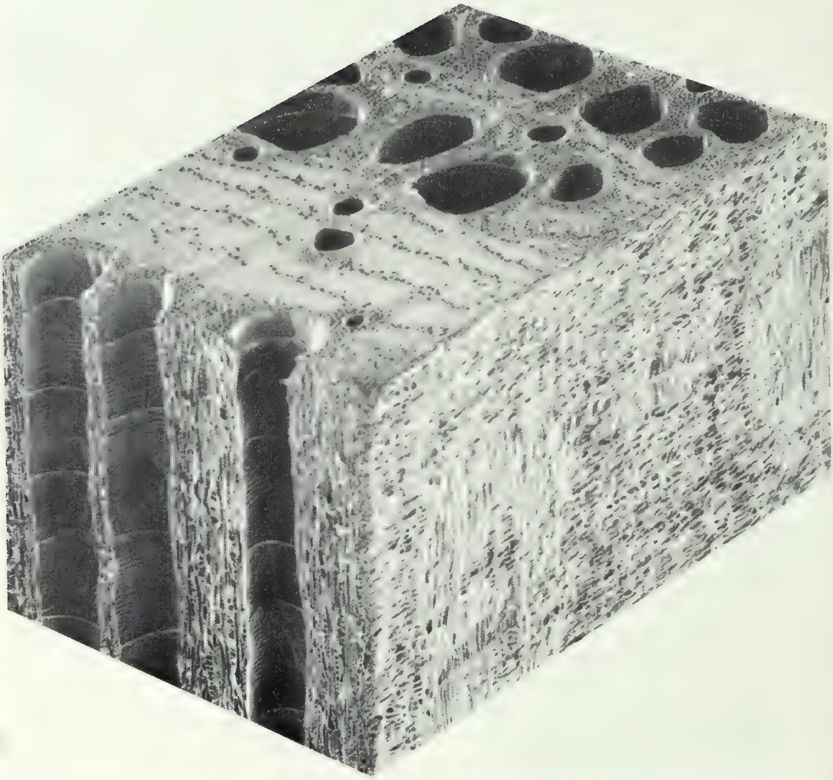


Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE	
Volume *(million cubic feet)*	
Percent of total hardwood volume on southern pine sites	
STEMWOOD	
Specific gravity *(ovendry weight and green volume)*	0.638
Weight of bark-free stemwood when green *(lbs/ft³)*	69.4
Percent moisture content of green wood *(ovendry basis)*	74.2
BARK	
Specific gravity *(ovendry weight and green volume)*	0.642
Percent moisture content of green bark *(ovendry basis)*	43.6

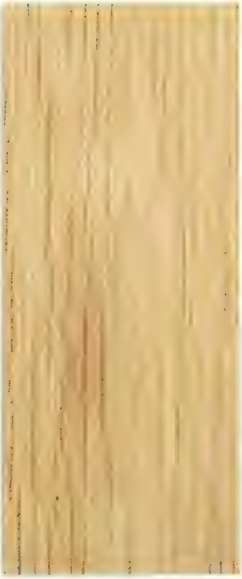


Mag. × 100

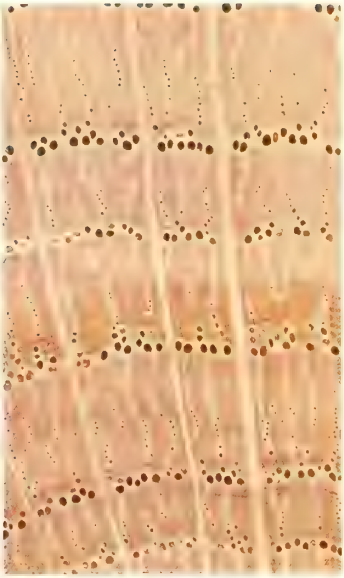
CHERRYBARK OAK

Quercus falcata var. *pagodaefolia* Ell.

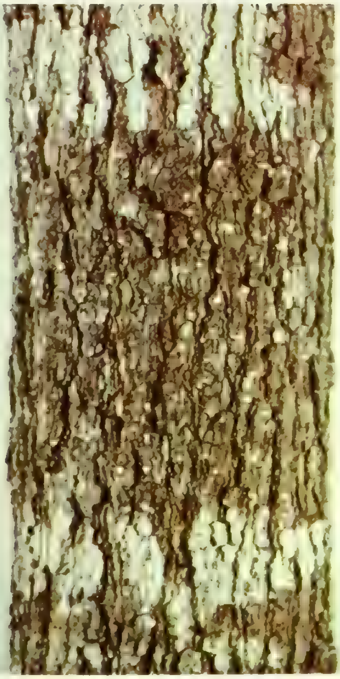
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

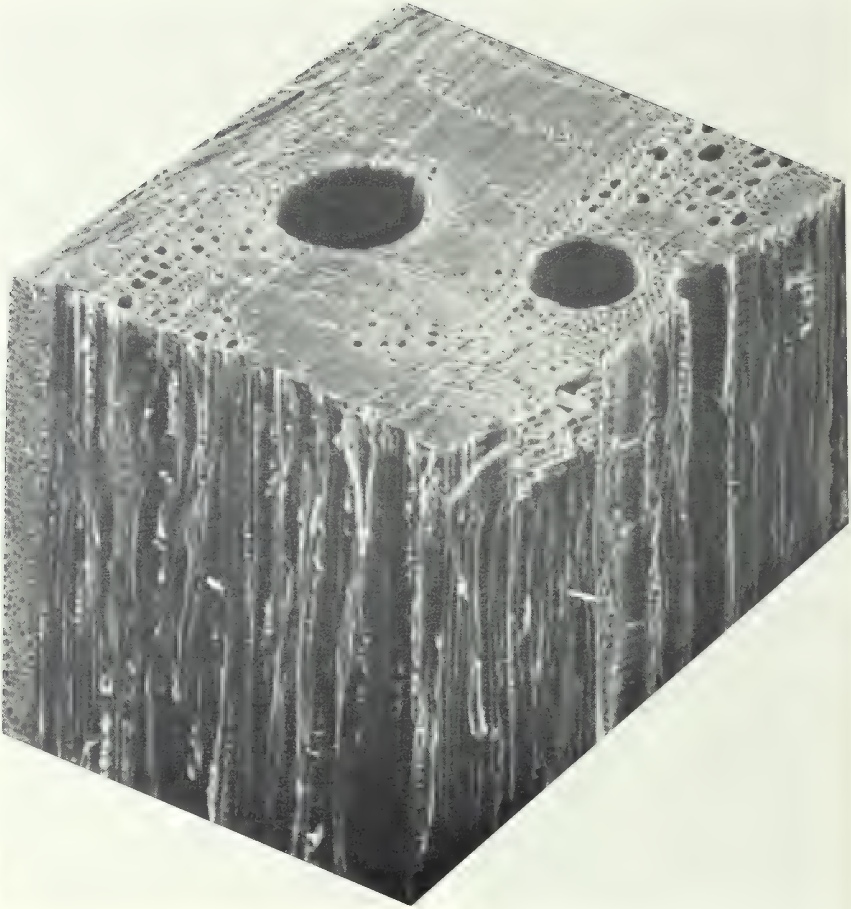
Volume *(million cubic feet)*	579
Percent of total hardwood volume on southern pine sites	1.2

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.623
Weight of bark-free stemwood when green *(lbs/ft^3)*	64.8
Percent moisture content of green wood *(ovendry basis)*	66.6

BARK

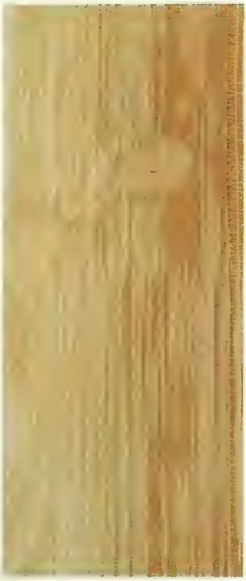
Specific gravity *(ovendry weight and green volume)*	0.622
Percent moisture content of green bark *(ovendry basis)*	54.1



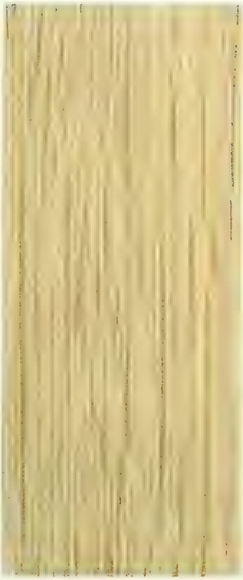
Mag. × 100

CHESTNUT OAK

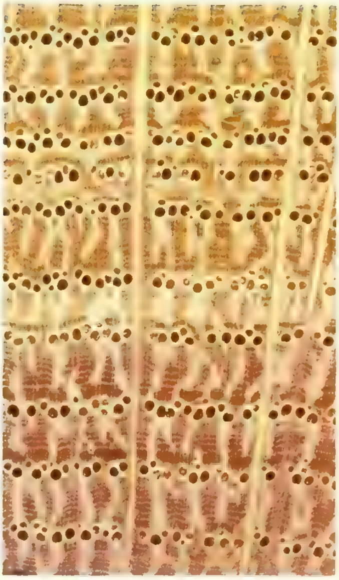
Quercus prinus L.



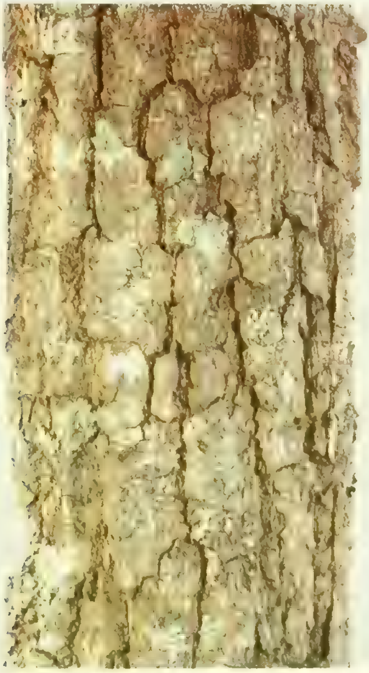
Radial
Mag. ×1



Tangential
Mag. ×1

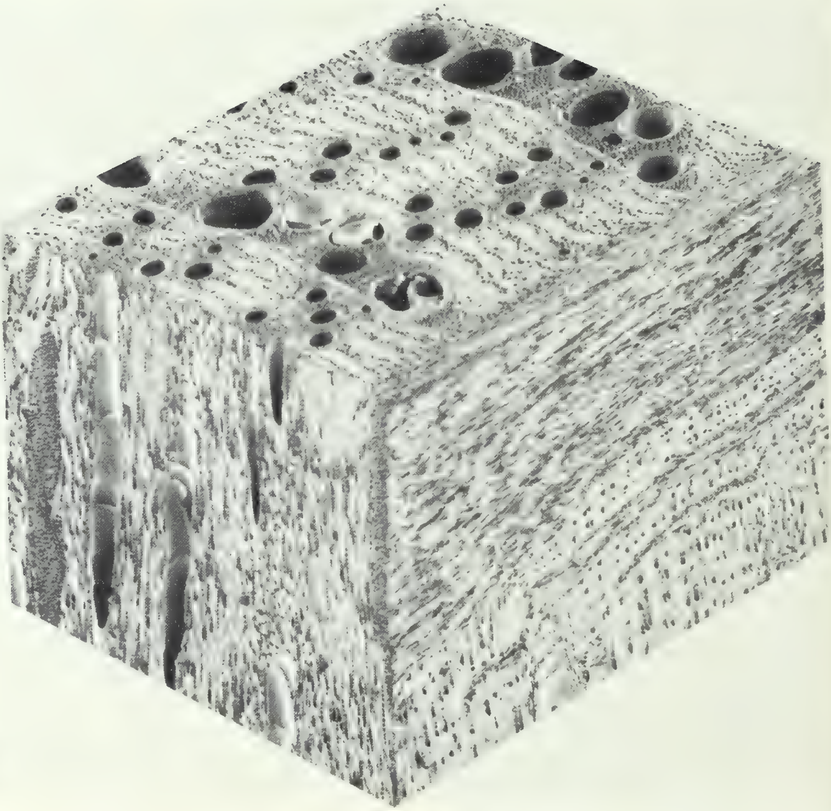


Transverse
Mag. ×5



Bark
Mag. ×0.3

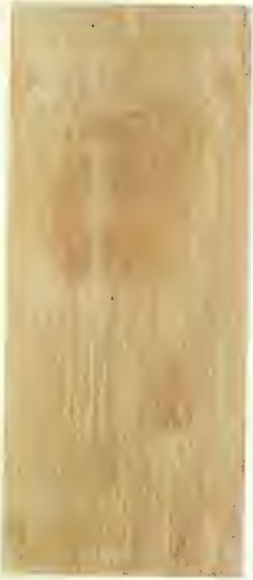
RESOURCE	
Volume *(million cubic feet)*	2102
Percent of total hardwood volume on southern pine sites	4.2
STEMWOOD	
Specific gravity *(ovendry weight and green volume)*	
Weight of bark-free stemwood when green *(lbs/ft³)*	
Percent moisture content of green wood *(ovendry basis)*	
BARK	
Specific gravity *(ovendry weight and green volume)*	
Percent moisture content of green bark *(ovendry basis)*	



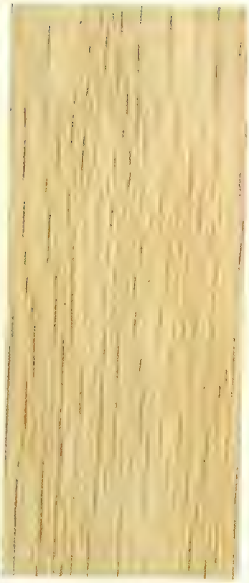
Mag. × 100

LAUREL OAK

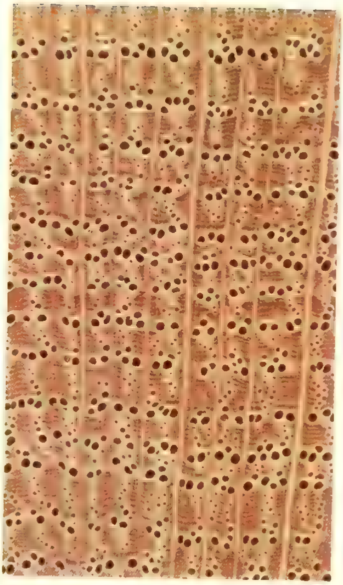
Quercus laurifolia Michx.



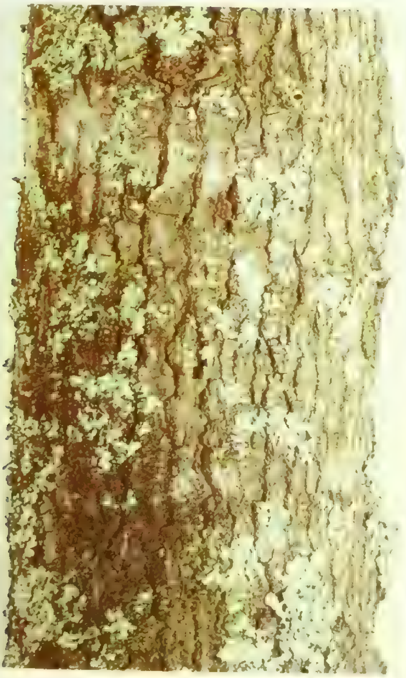
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

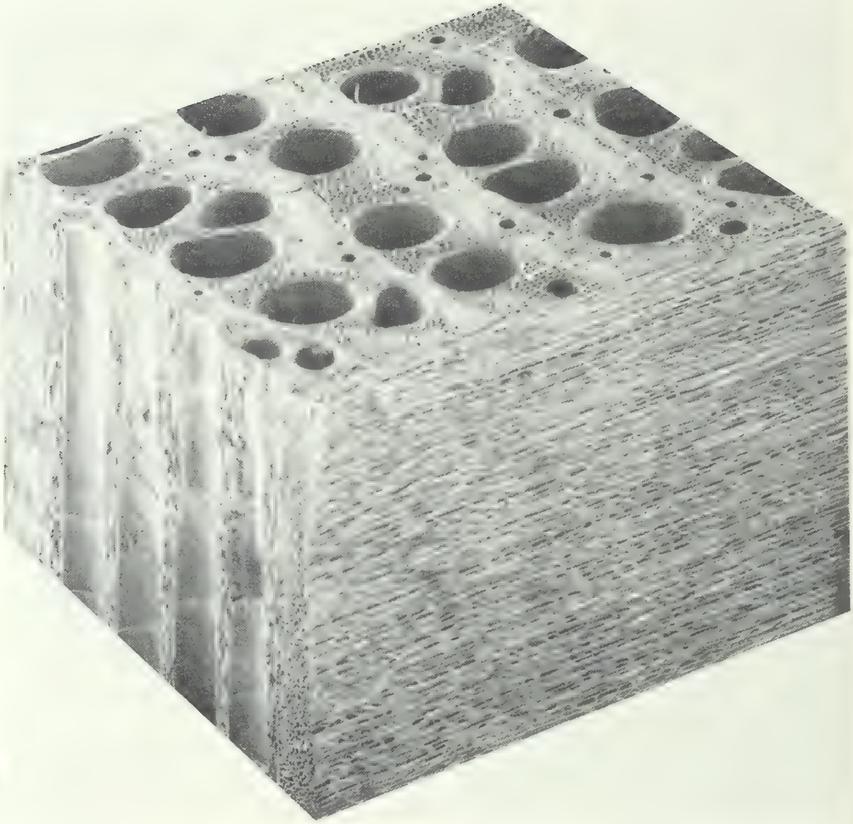
Volume *(million cubic feet)*	683
Percent of total hardwood volume on southern pine sites	1.4

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.582
Weight of bark-free stemwood when green *(lbs/ft^3)*	63.4
Percent moisture content of green wood *(ovendry basis)*	74.4

BARK

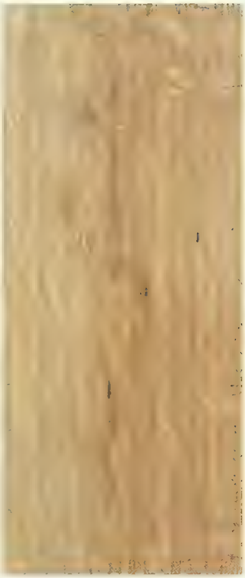
Specific gravity *(ovendry weight and green volume)*	0.630
Percent moisture content of green bark *(ovendry basis)*	57.4



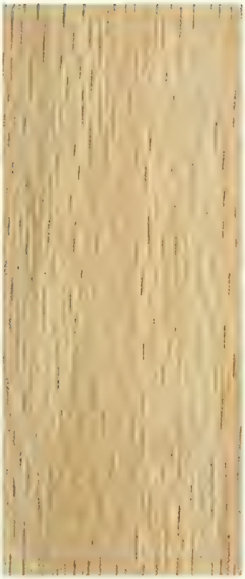
Mag. × 100

NORTHERN RED OAK

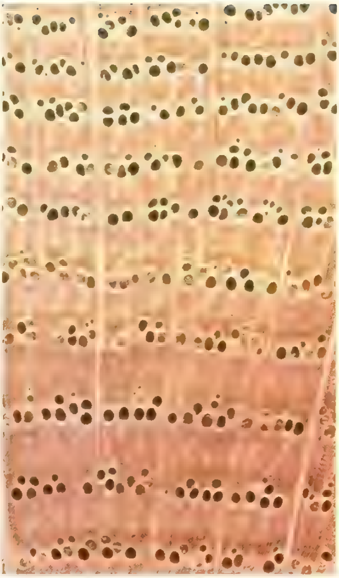
Quercus rubra L.



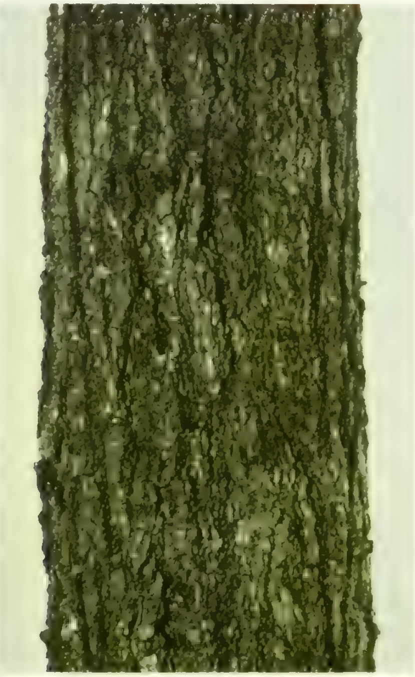
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

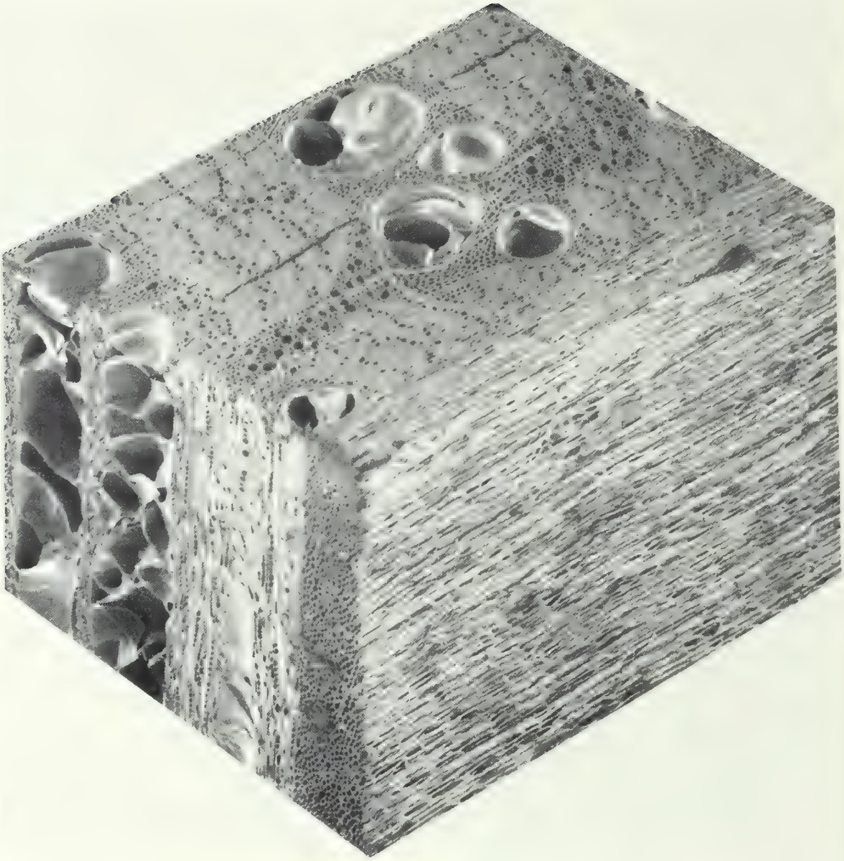
Volume *(million cubic feet)*	1169
Percent of total hardwood volume on southern pine sites	2.4

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.605
Weight of bark-free stemwood when green *(lbs/ft^3)*	64.1
Percent moisture content of green wood *(ovendry basis)*	69.7

BARK

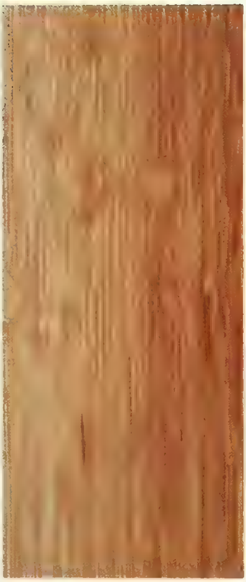
Specific gravity *(ovendry weight and green volume)*	0.644
Percent moisture content of green bark *(ovendry basis)*	55.7



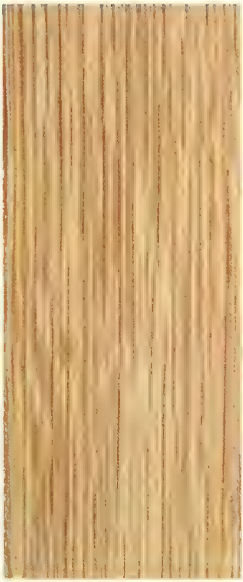
Mag. × 100

POST OAK

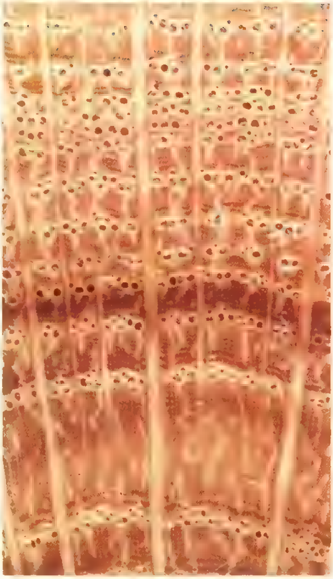
Quercus stellata Wangenh.



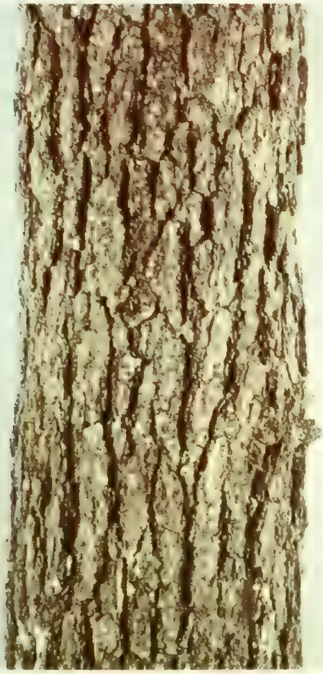
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

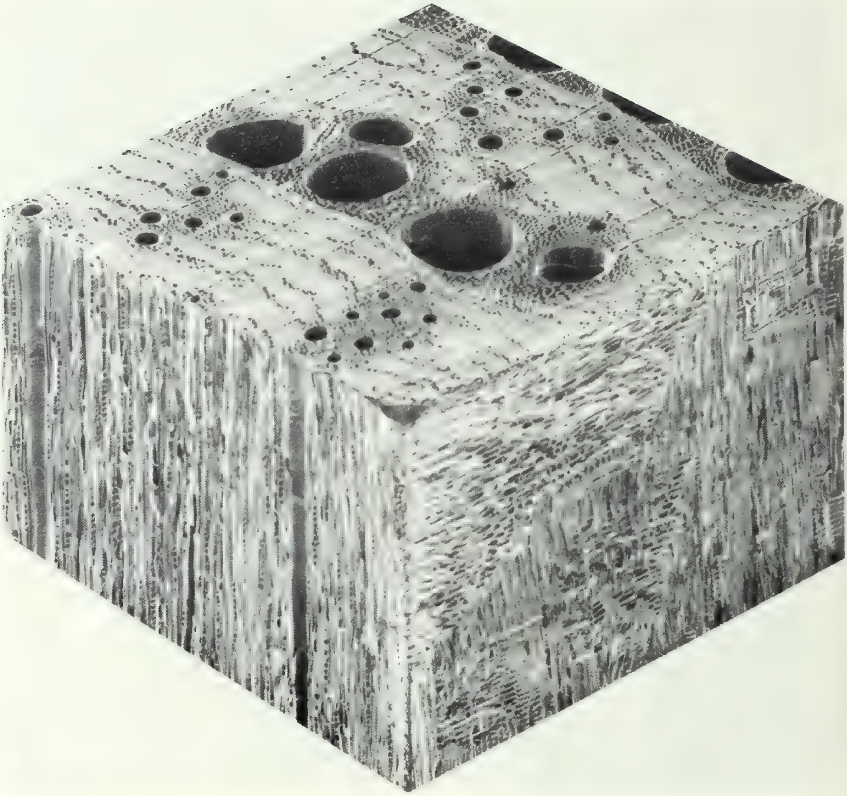
Volume *(million cubic feet)*	3444
Percent of total hardwood volume on southern pine sites	7.0

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.659
Weight of bark-free stemwood when green *(lbs/ft³)*	68.1
Percent moisture content of green wood *(ovendry basis)*	65.6

BARK

Specific gravity *(ovendry weight and green volume)*	0.498
Percent moisture content of green bark *(ovendry basis)*	48.9



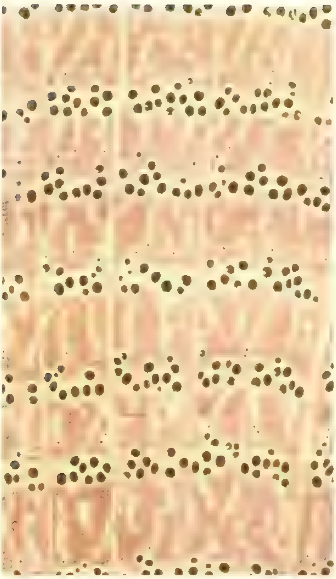
Mag. × 100

SCARLET OAK

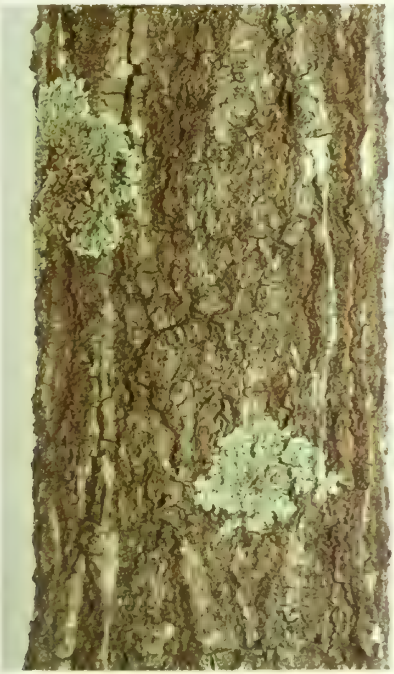
Quercus coccinea Muenchh.

Radial
Mag. ×1

Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

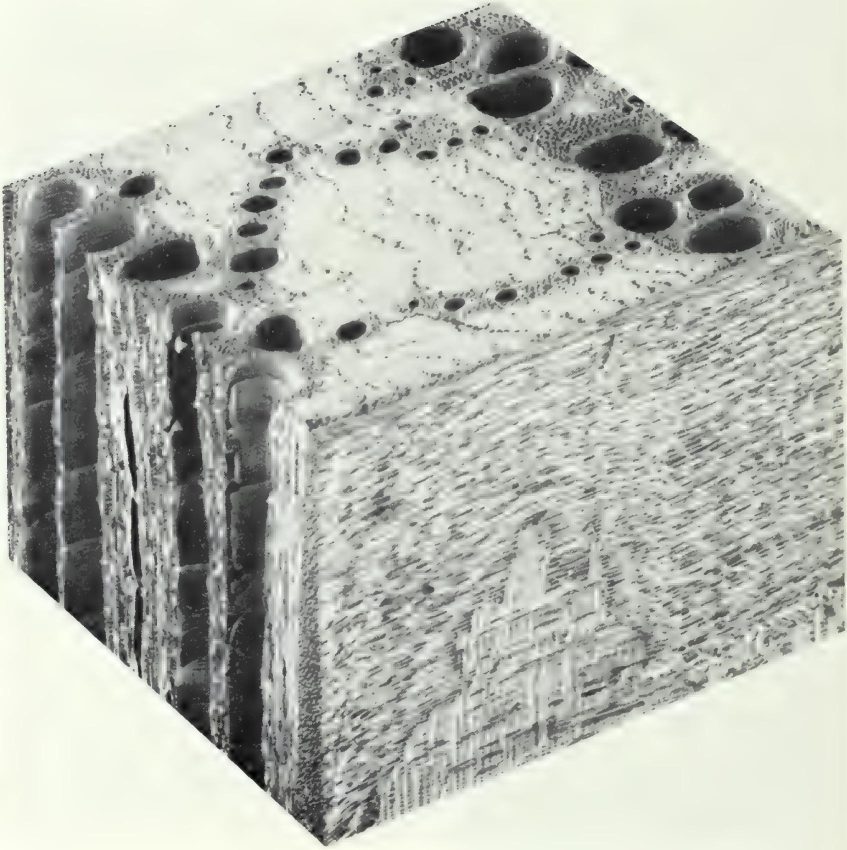
Volume *(million cubic feet)*	1799
Percent of total hardwood volume on southern pine sites	3.6

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.622
Weight of bark-free stemwood when green *(lbs/ft^3)*	65.8
Percent moisture content of green wood *(ovendry basis)*	69.4

BARK

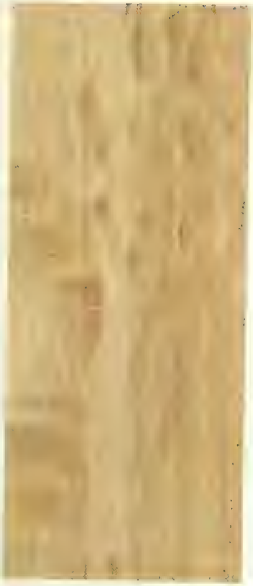
Specific gravity *(ovendry weight and green volume)*	0.618
Percent moisture content of green bark *(ovendry basis)*	55.6



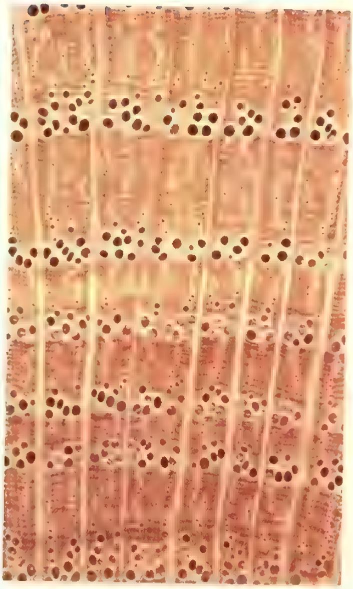
Mag. × 100

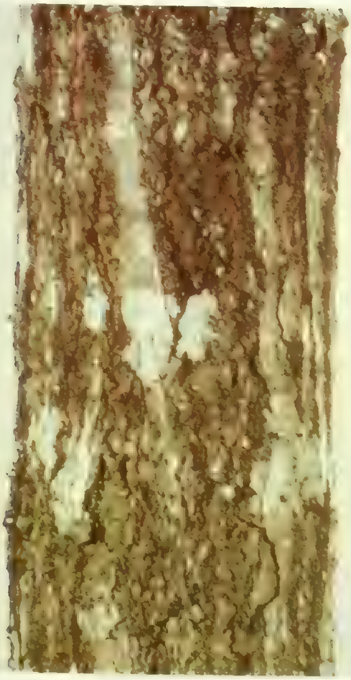
SHUMARD OAK

Quercus shumardii Buckl.


Radial
Mag. ×1

Tangential
Mag. ×1


Transverse
Mag. ×5


Bark
Mag. ×0.3

RESOURCE

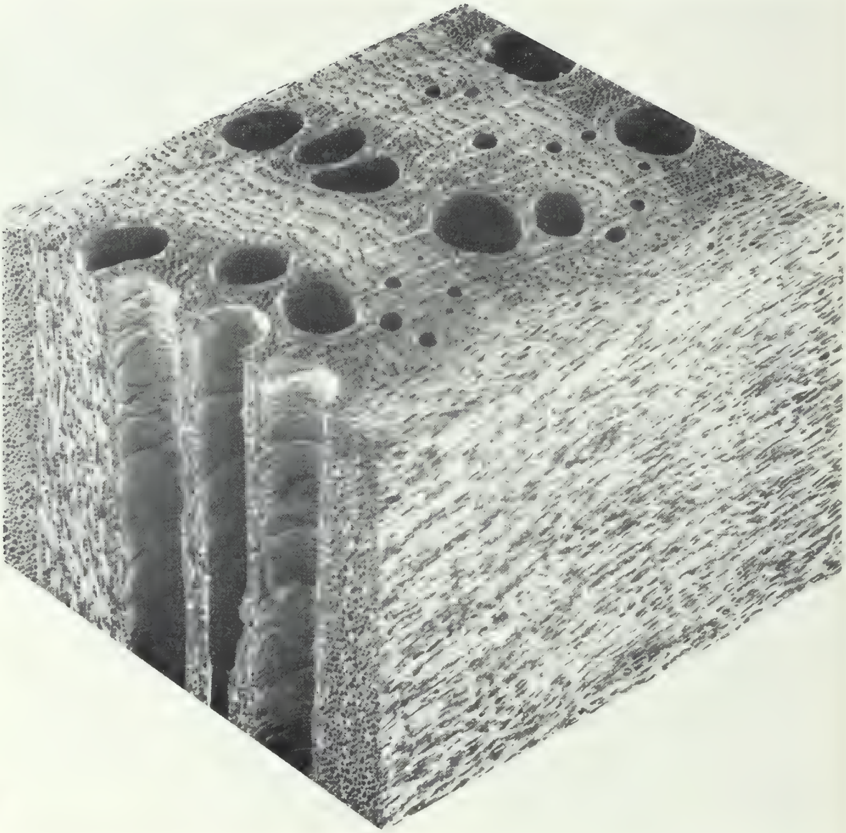
Volume *(million cubic feet)*	120
Percent of total hardwood volume on southern pine sites	0.2

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.625
Weight of bark-free stemwood when green *(lbs/ft^3)*	66.0
Percent moisture content of green wood *(ovendry basis)*	69.1

BARK

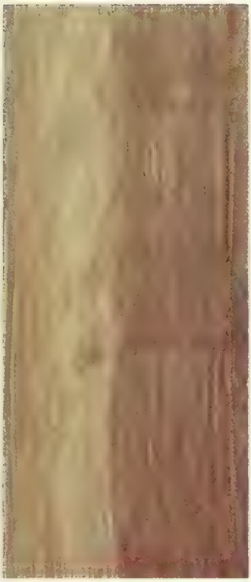
Specific gravity *(ovendry weight and green volume)*	0.644
Percent moisture content of green bark *(ovendry basis)*	52.2



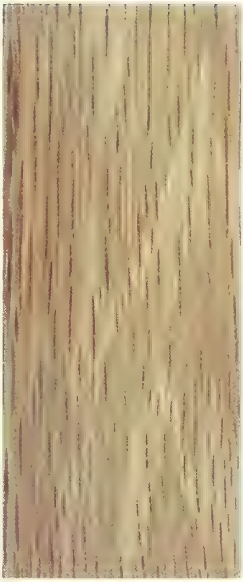
Mag. × 100

SOUTHERN RED OAK

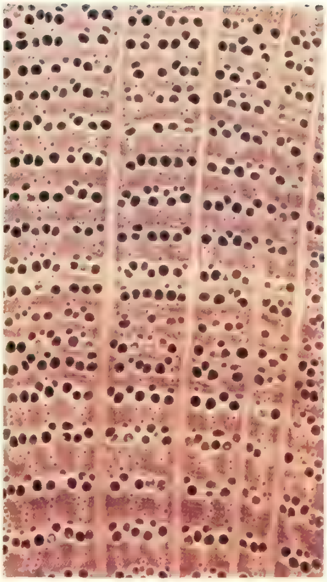
Quercus falcata Michx. var. *falcata*



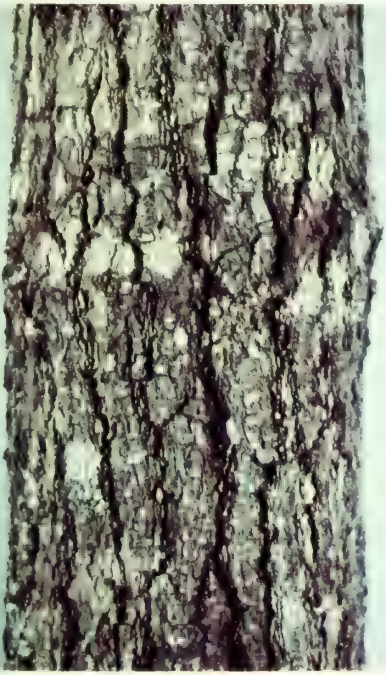
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

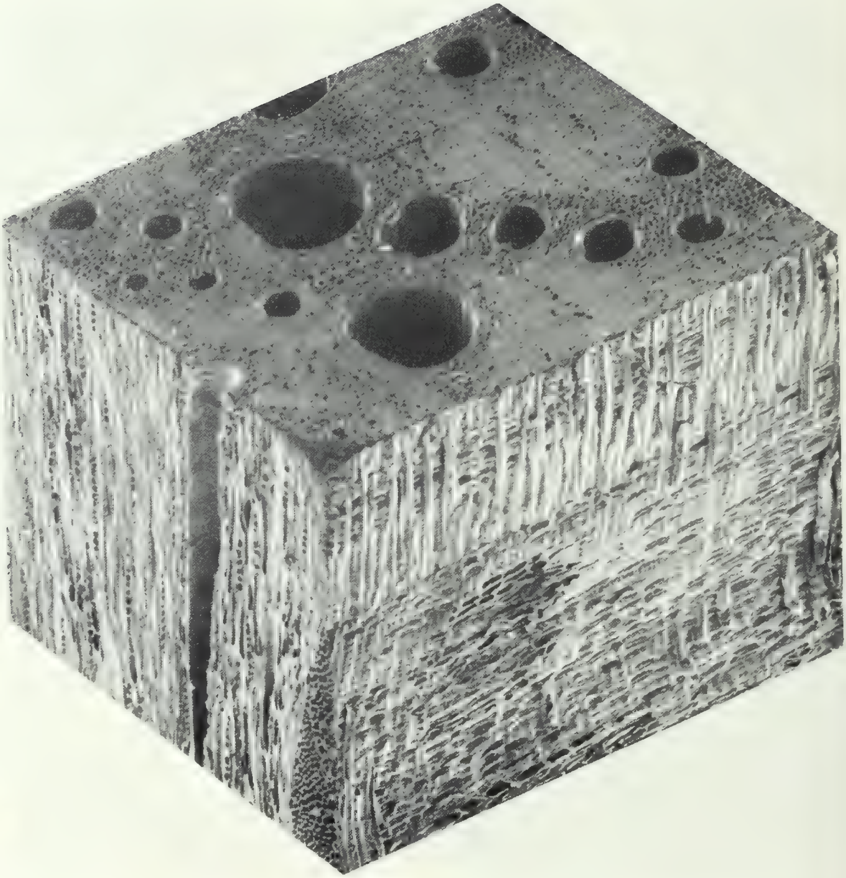
Volume *(million cubic feet)*	3994
Percent of total hardwood volume on southern pine sites	8.1

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.609
Weight of bark-free stemwood when green *(lbs/ft^3)*	64.7
Percent moisture content of green wood *(ovendry basis)*	70.1

BARK

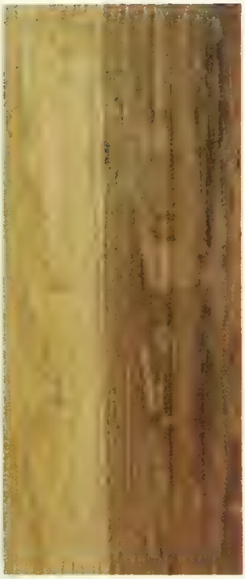
Specific gravity *(ovendry weight and green volume)*	0.601
Percent moisture content of green bark *(ovendry basis)*	52.9

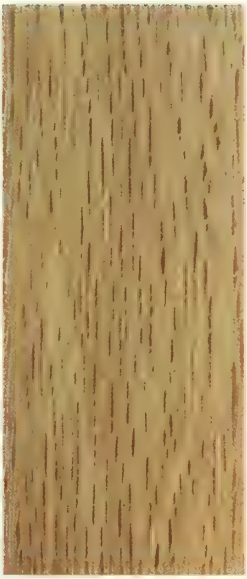


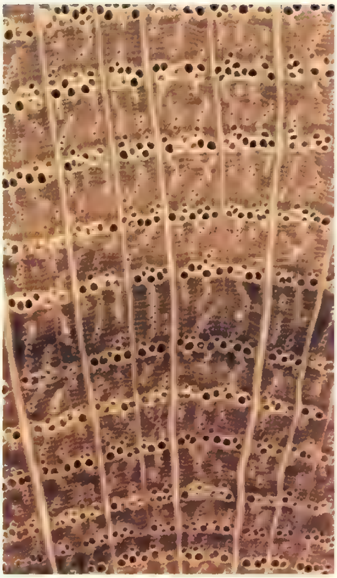
Mag. × 100

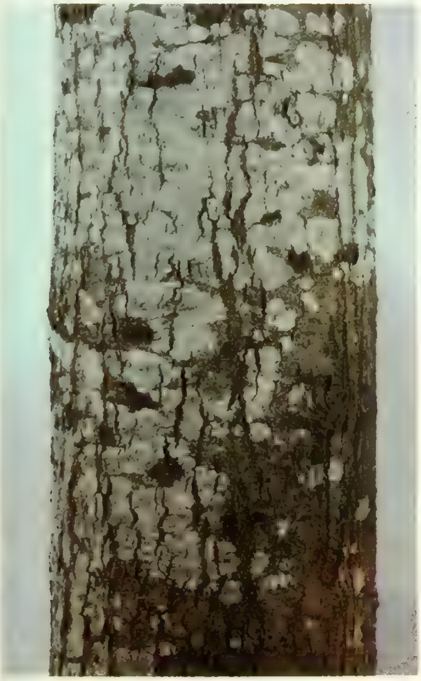
WATER OAK

Quercus nigra L.


Radial
Mag. ×1


Tangential
Mag. ×1


Transverse
Mag. ×5


Bark
Mag. ×0.3

RESOURCE

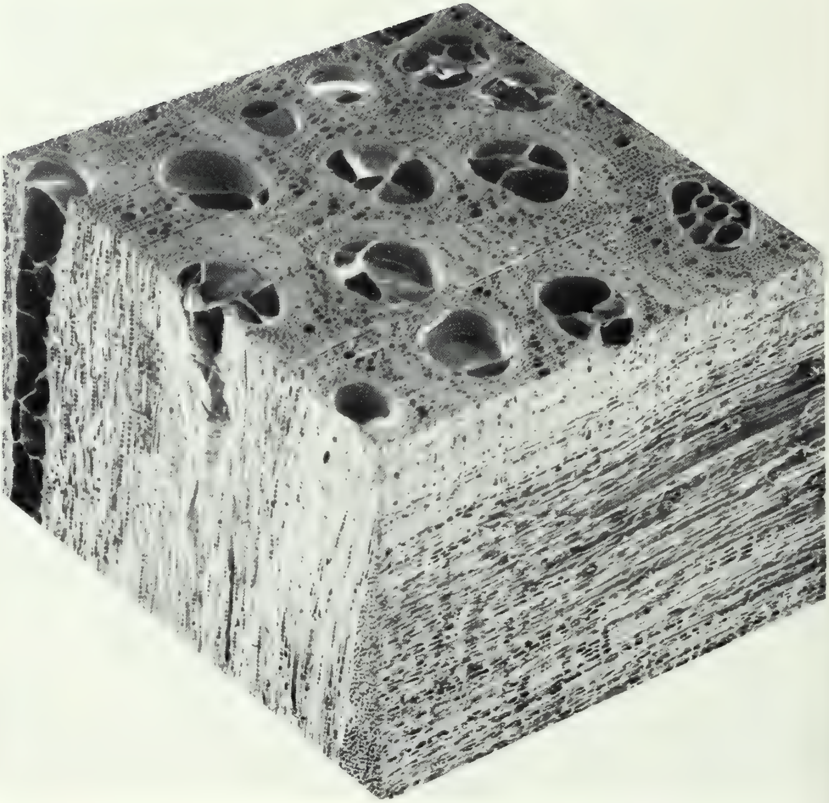
Volume *(million cubic feet)*	2332
Percent of total hardwood volume on southern pine sites	4.7

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.587
Weight of bark-free stemwood when green *(lbs/ft^3)*	63.6
Percent moisture content of green wood *(ovendry basis)*	73.6

BARK

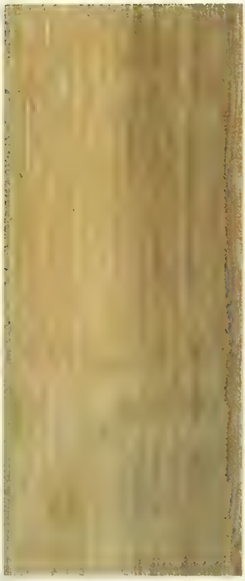
Specific gravity *(ovendry weight and green volume)*	0.628
Percent moisture content of green bark *(ovendry basis)*	54.4



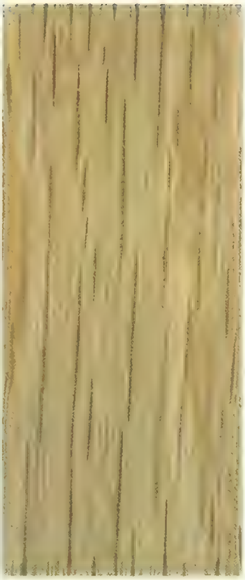
Mag. × 100

WHITE OAK

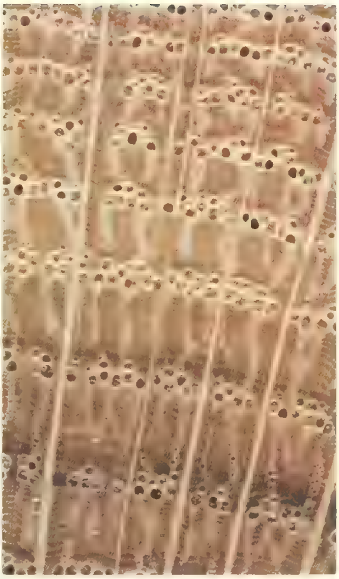
Quercus alba L.



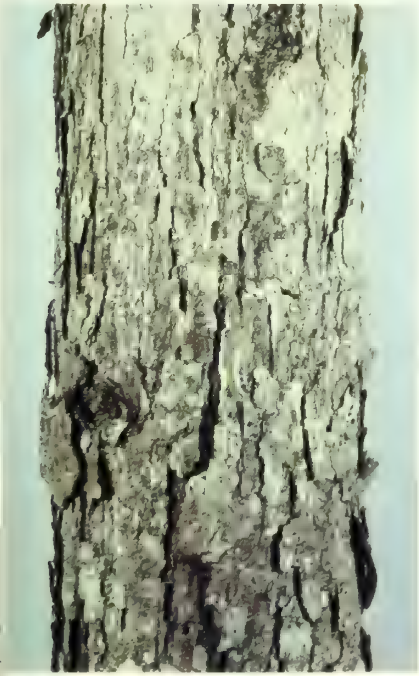
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

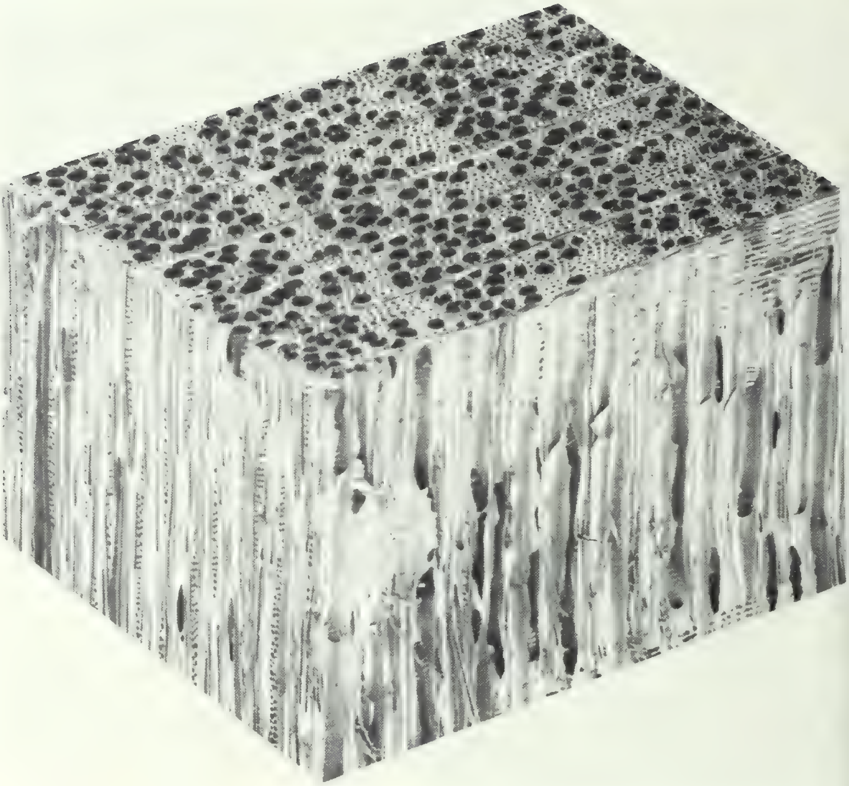
Volume *(million cubic feet)*	6058
Percent of total hardwood volume on southern pine sites	12.3

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.665
Weight of bark-free stemwood when green *(lbs/ft^3)*	67.2
Percent moisture content of green wood *(ovendry basis)*	61.9

BARK

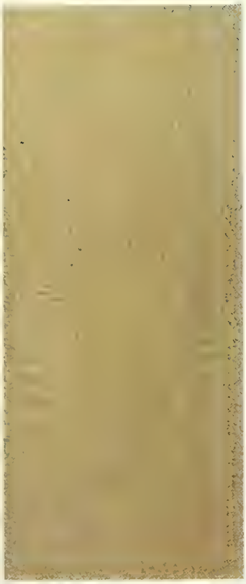
Specific gravity *(ovendry weight and green volume)*	0.543
Percent moisture content of green bark *(ovendry basis)*	58.1



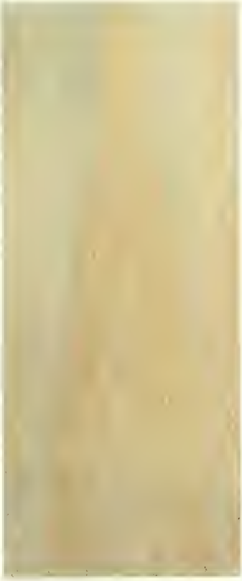
Mag. × 100

SWEETBAY

Magnolia virginiana L.

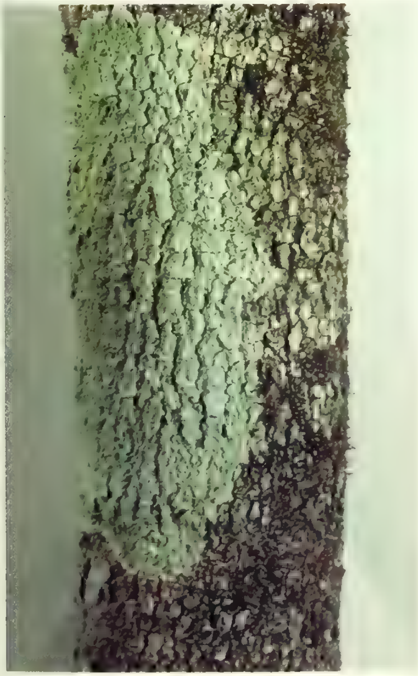


Radial
Mag. ×1



Tangential
Mag. ×1

Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

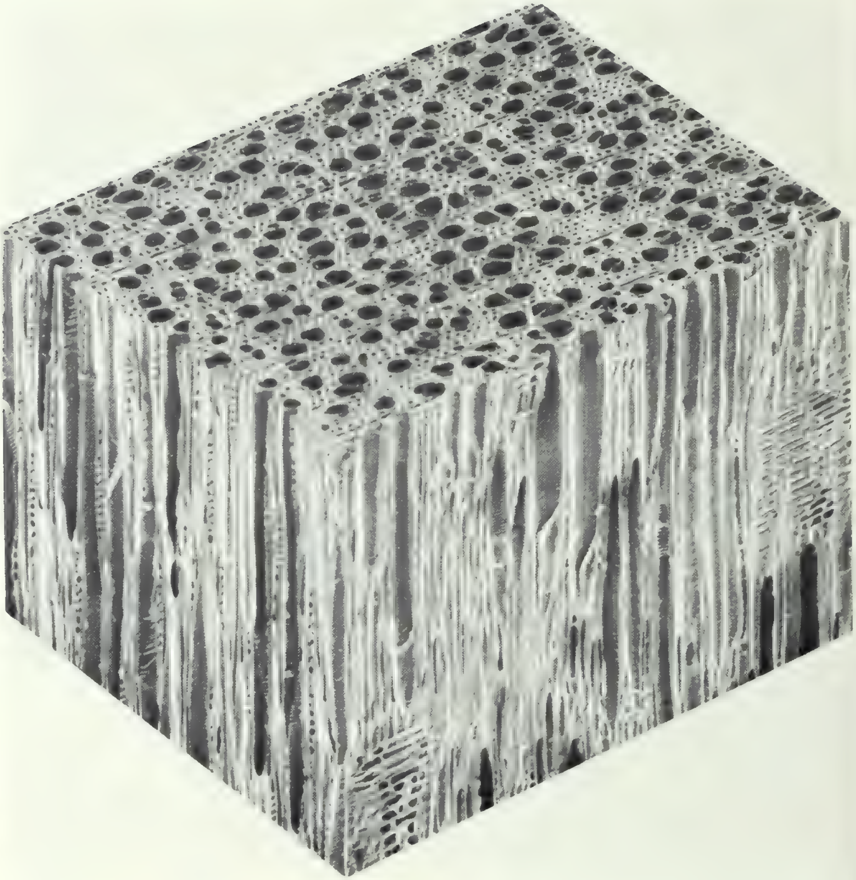
Volume *(million cubic feet)*	300
Percent of total hardwood volume on southern pine sites	0.6

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.437
Weight of bark-free stemwood when green *(lbs/ft^3)*	54.8
Percent moisture content of green wood *(ovendry basis)*	100.8

BARK

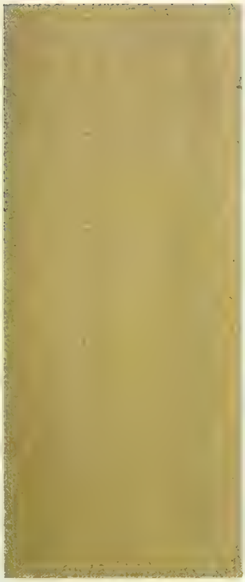
Specific gravity *(ovendry weight and green volume)*	0.440
Percent moisture content of green bark *(ovendry basis)*	102.1



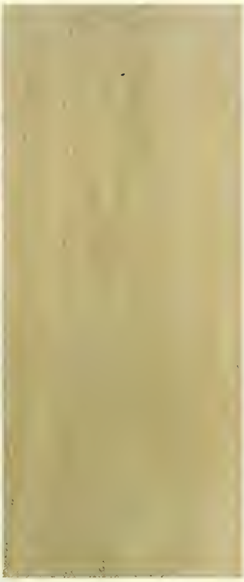
Mag. × 100

SWEETGUM

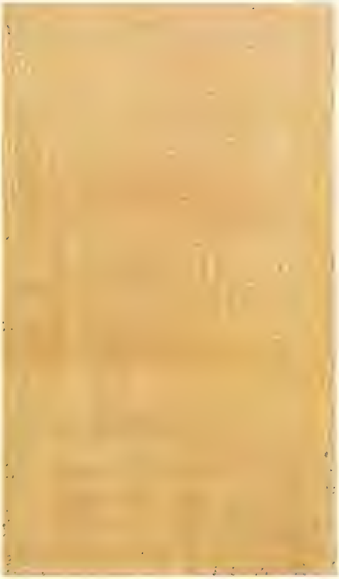
Liquidambar styraciflua L.



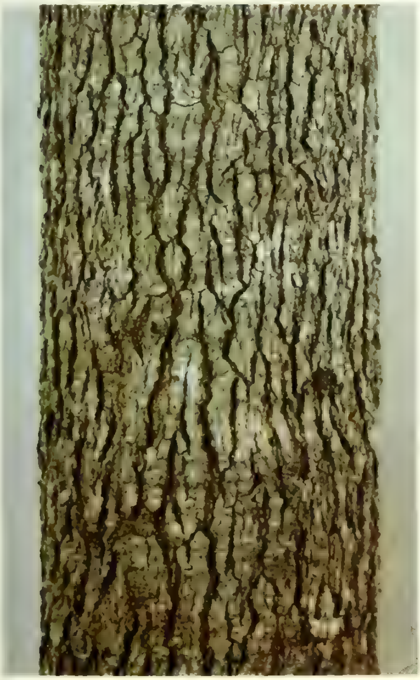
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE

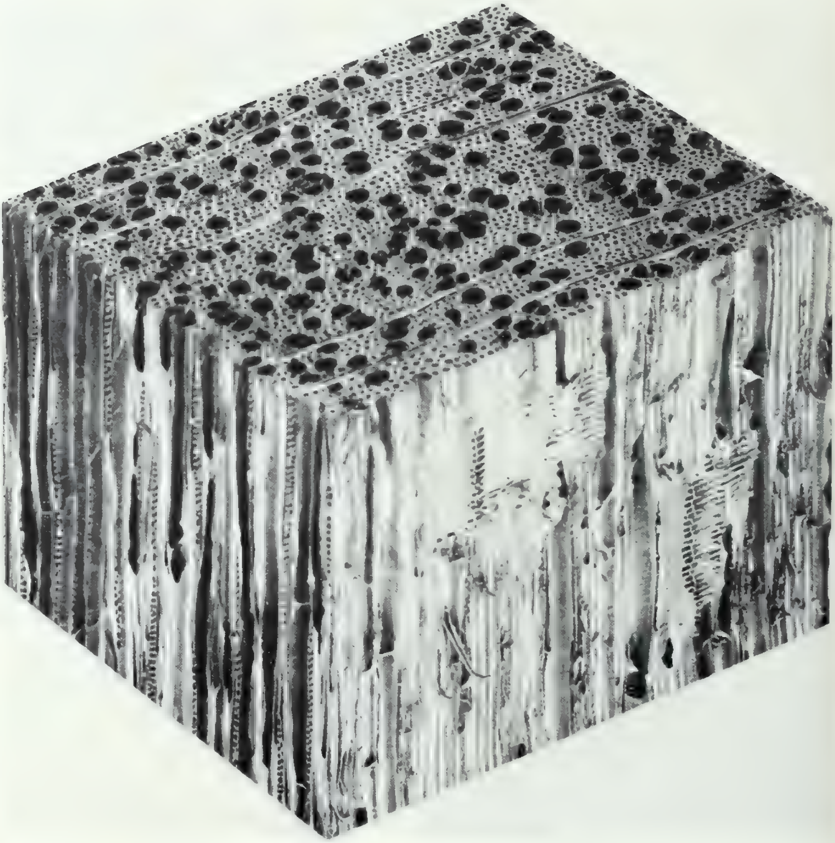
Volume *(million cubic feet)*	6508
Percent of total hardwood volume on southern pine sites	13.2

STEMWOOD

Specific gravity *(ovendry weight and green volume)*	0.453
Weight of bark-free stemwood when green *(lbs/ft³)*	62.3
Percent moisture content of green wood *(ovendry basis)*	120.4

BARK

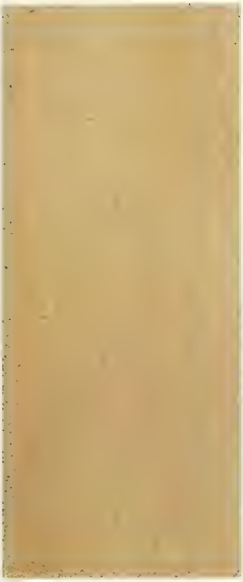
Specific gravity *(ovendry weight and green volume)*	0.369
Percent moisture content of green bark *(ovendry basis)*	89.3



Mag. × 100

BLACK TUPELO

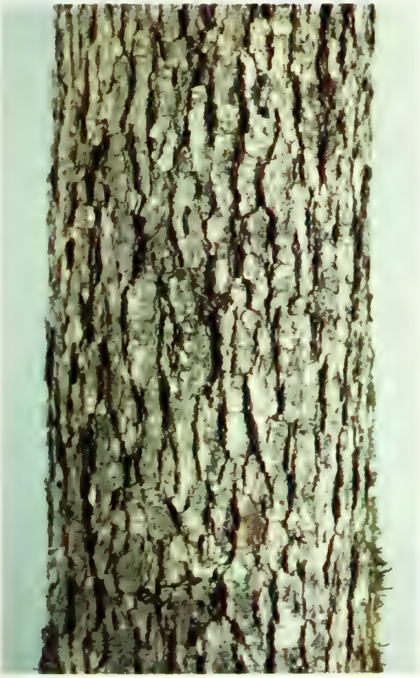
Nyssa sylvatica Marsh.



Radial
Mag. ×1

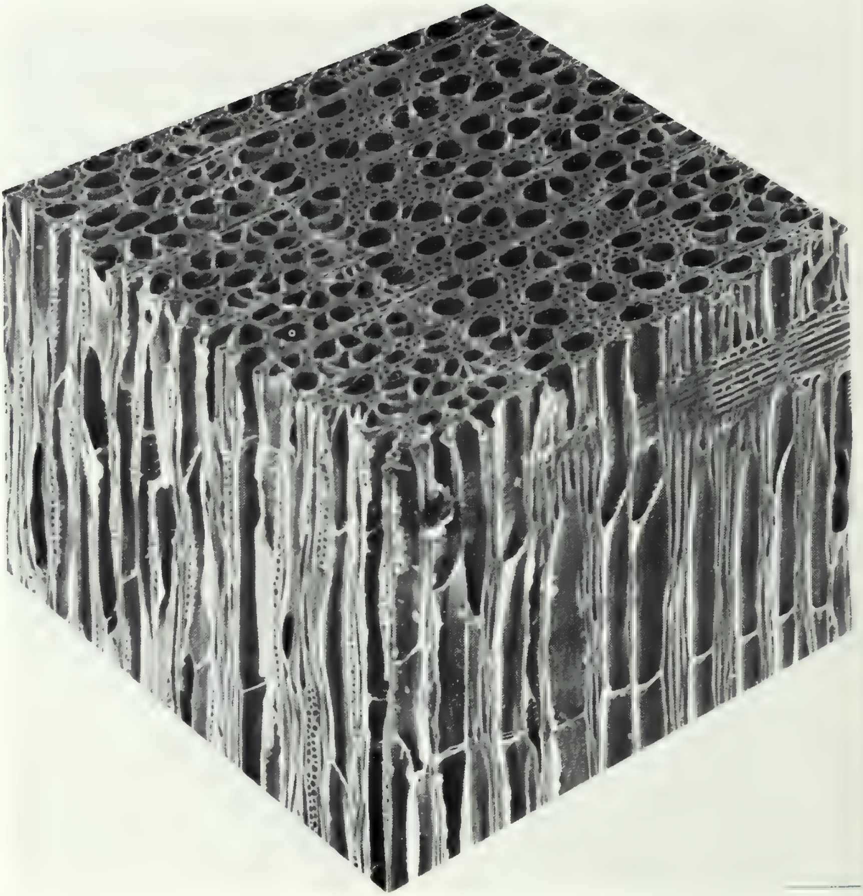
Tangential
Mag. ×1

Transverse
Mag. ×5



Bark
Mag. ×0.3

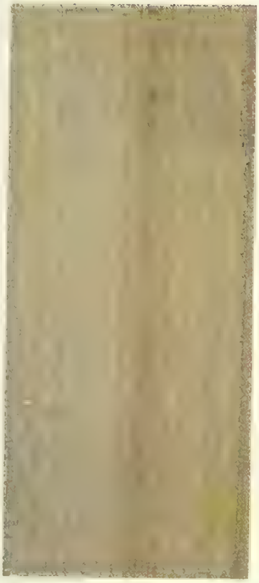
RESOURCE	
Volume *(million cubic feet)*	2710
Percent of total hardwood volume on southern pine sites	5.5
STEMWOOD	
Specific gravity *(ovendry weight and green volume)*	0.500
Weight of bark-free stemwood when green *(lbs/ft³)*	59.3
Percent moisture content of green wood *(ovendry basis)*	90.0
BARK	
Specific gravity *(ovendry weight and green volume)*	0.428
Percent moisture content of green bark *(ovendry basis)*	69.8



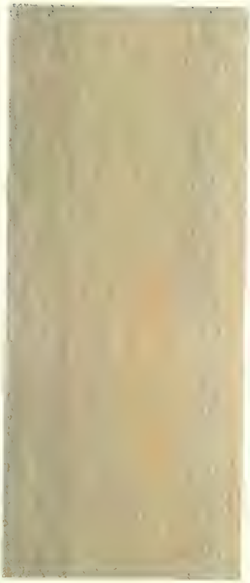
Mag. × 100

YELLOW-POPLAR

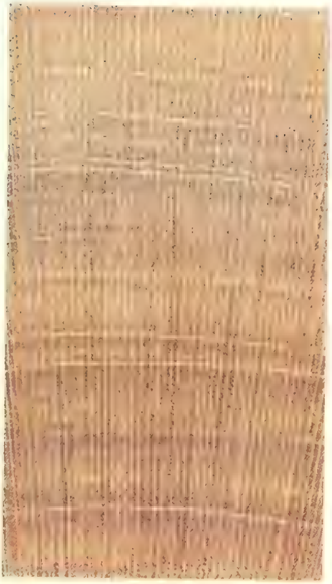
Liriodendron tulipifera L.



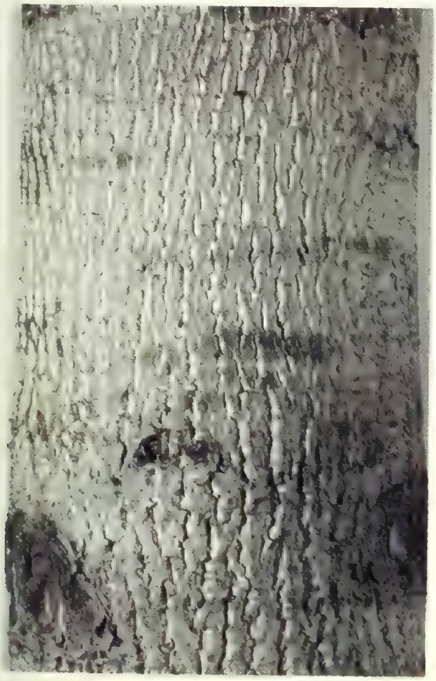
Radial
Mag. ×1



Tangential
Mag. ×1



Transverse
Mag. ×5



Bark
Mag. ×0.3

RESOURCE	
Volume *(million cubic feet)*	3421
Percent of total hardwood volume on southern pine sites	7.0
STEMWOOD	
Specific gravity *(ovendry weight and green volume)*	0.395
Weight of bark-free stemwood when green *(lbs/ft³)*	52.2
Percent moisture content of green wood *(ovendry basis)*	111.7
BARK	
Specific gravity *(ovendry weight and green volume)*	0.390
Percent moisture content of green bark *(ovendry basis)*	125.8

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1980. The wood and bark of hardwoods growing on southern pine sites – A pictorial atlas. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-29, 58 p. South. For. Exp. Stn. New Orleans, La.

Provides a pictorial description of the structure and appearance of 23 pine-site hardwoods, an overview of hardwood anatomy, and data on the resource and certain important physical properties of stemwood and bark.

Additional keywords: Southern hardwoods, anatomy, structure, color, appearance, wood properties, bark properties.

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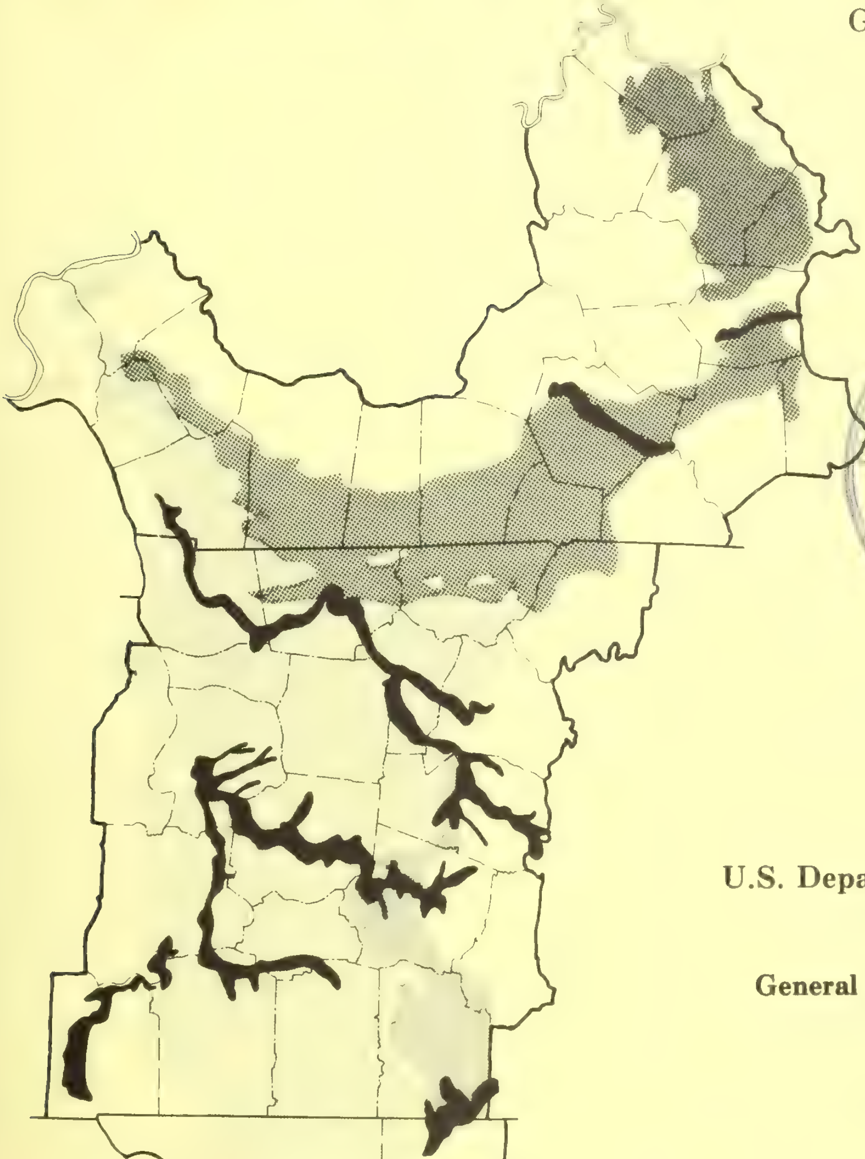
Classification and Evaluation of Forest Sites on the Western Highland Rim and Pennyroyal

Glendon W. Smalley



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U.S. Department of Agriculture
Forest Service

General Technical Report SO-30

Southern
Forest
Experiment
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SUMMARY

This paper presents a comprehensive forest site classification system for the Western Highland Rim and Western Pennyroyal-Limestone area in northern Alabama, central Tennessee, and western Kentucky. The system is based on physiography, geology, soils, topography, and vegetation. Forty-nine landtypes are described, and each landtype is evaluated in terms of productivity and desirability of selected pines and hardwoods for timber production. Also, each landtype is rated for five soil-related problems that can affect forest management.

ACKNOWLEDGMENTS

I am indebted to my colleagues, past and present, for their scientific input, reviews, and stimulating discussions. I am also grateful to the soil scientists, silviculturists, and practicing foresters who have reviewed this guide.

1980

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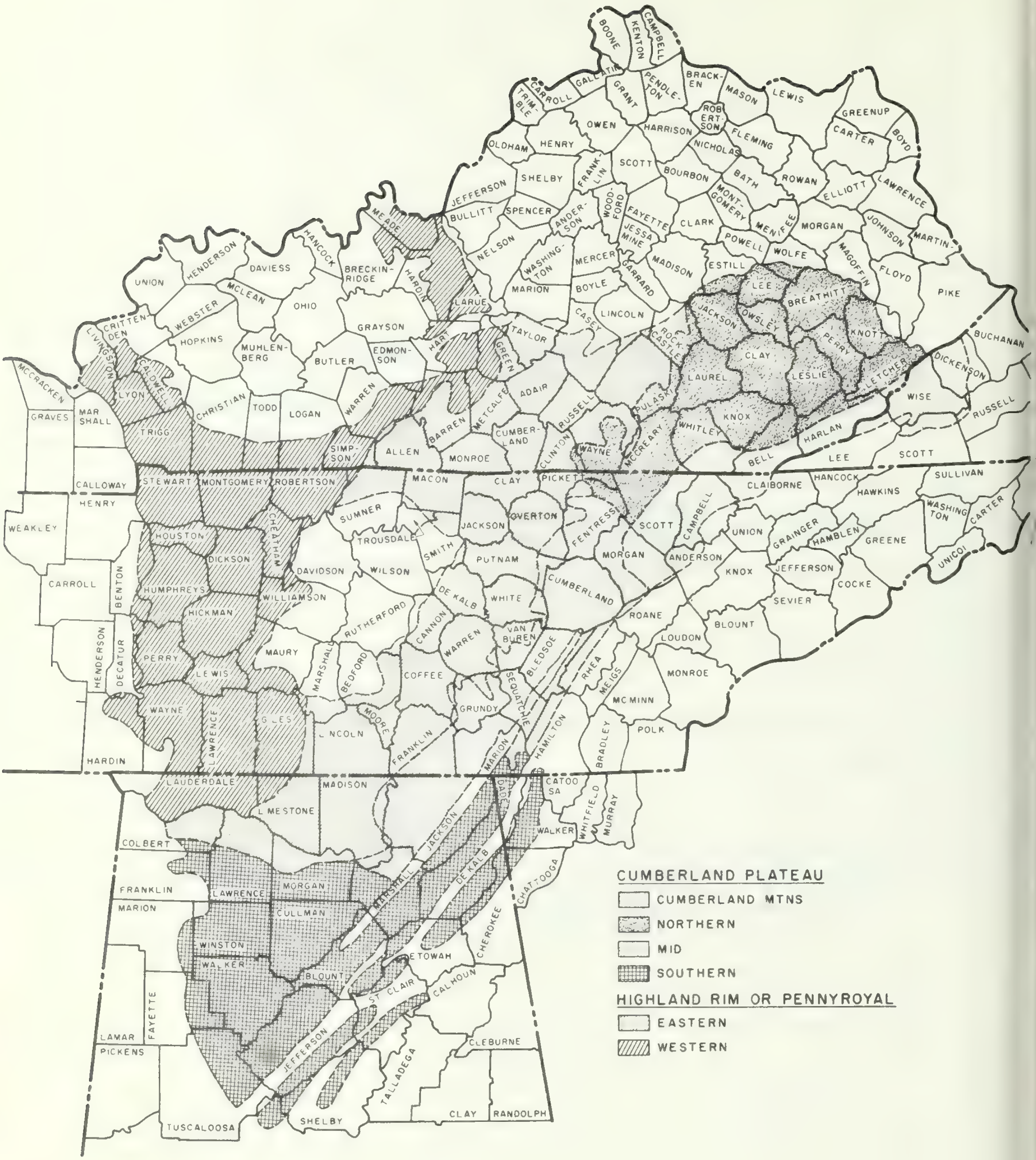

Figure 1.—*Physiographic provinces and regions of the Interior Uplands.*

Classification and Evaluation of Forest Sites on the Western Highland Rim and Pennyroyal

Glendon W. Smalley

INTRODUCTION

This report classifies and evaluates forest sites on ie Western Highland Rim and Western Penny- yal-Limestone Area (fig. 1) for the management several commercially valuable tree species. It ovides forest managers with a land classification stem that will enable them to subdivide forest nd into logical segments (landtypes), allow them rate productivity, and alert them to any limita- ons and hazards that the landtypes impose on rest management. Though soils information is an tegral part of this system, users will not need to entify and classify soils or to make laboratory eterminations. This report is oriented to timber oduction because timber is usually a major man- gement objective. However, landtypes can also be ie basis for the management and interpretation of her forest resources.

I have drawn freely on much published informa- on on geology, physiography, soils, sites, and elds. In many cases, data specific to this area were ot available, and information was extrapolated om adjacent regions. Extrapolation was particu- rly necessary with productivity data. All sources data are documented so the user can gage the curacy and reliability of the information.

Productivity and management problem infor- ation is presented in a format that follows the utline used by the Soil Conservation Service SCS) in the Woodland Suitability sections of unty soil surveys. This similarity should facili- ate the integration of information contained in unty soil surveys[1] into this classification system.

This guide represents the best information and llective judgment now available. Nevertheless, it still incomplete. I trust that forest managers, after applying this site classification system, will share their experience with me and make me aware of any shortcomings or needed revisions.

The rationale and methodology for the developament of a site classification system for the Interior Uplands appeared in the proceedings of the Second Central Hardwood Forest Conference (Smalley 1978) and the Forest Soils and Site Quality Workshop (Smalley 1979a). A site classification guide for the Southern Cumberland Plateau Region has been published (Smalley 1979b).

WESTERN HIGHLAND RIM AND PENNYROYAL REGION

The Western Highland Rim and Pennyroyal region covers about 10,850 square miles in all or portions of 2 counties in Alabama, 18 in Kentucky, and 20 in Tennessee. The region extends south to north from about north latitude 34°45′ to 38°3′ and east to west from about west longitude 86°35′ to 88°15′. It extends from the Ohio River in Meade County, Kentucky, to the Tennessee River in Lauderdale County, Alabama, a distance of about 220 miles (fig. 2).

In Tennessee the Western Highland Rim includes the upland that surrounds the Nashville Basin on the west (Fenneman 1938). Also included is the knobby transition from the Rim to the Basin and interspersed portions of the Outer Basin. The Western Highland Rim extends west of the Tennessee River in a narrow band from Henry to Hardin Counties while some of the Upper Coastal Plain physiographic province lies east of the River in the Land Between the Lakes, in Humphreys and Wayne Counties, Tennessee, and in Lauderdale County, Alabama.

In Alabama the Western Highland Rim extends

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[1] ee Appendix for available soil surveys.

nalley is Principal Soil Scientist at the Silviculture Laboratory, maintained at Sewanee, Tennessee, by the Southern Forest kperiment Station, Forest Service—USDA, in cooperation with the University of the South.

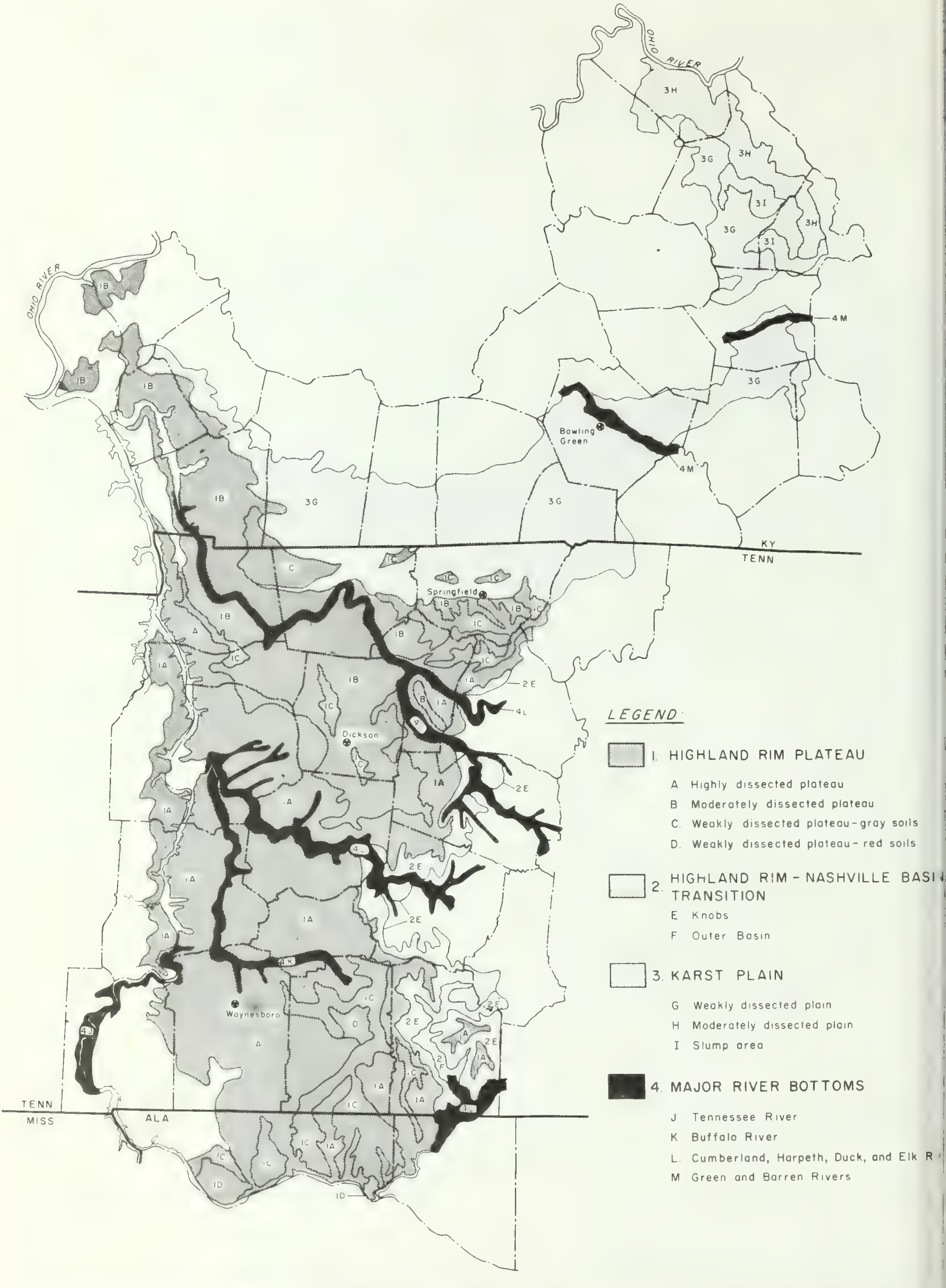

Figure 2.—*Subregions and landtype associations of the Western Highland Rim and Western Pennyroyal-Limestone area a location of weather stations.*

outhward to the Tennessee River. The arbitrary ivision between the Eastern and Western Rim in labama and Tennessee is the Elk River to near ellrose, Tennessee, and then north along the iles-Lincoln County line to the Nashville Basin ear Lewisburg, Tennessee.

In Kentucky this section is known as the Western ennyroyal-Limestone Area (Bailey and Winsor 964; Fenneman 1938; Soil Conserv. Serv. 1975). he section is named for the Pennyroyal of Amera (*Hedeoma pulegioides* (L.) Pens.), a wild member of the mint family that grows abundantly in he area. The Pennyroyal forms a broad horseshoe outh and east of the Western Coalfields and the andstone-Shale-Limestone area of the Western ennyroyal, and its boundary is the Dripping prings escarpment. North of the Green River, the Western Pennyroyal curves northwestward in a trip 15 to 20 miles wide between the Muldraugh's ill and Dripping Springs escarpments.

North of the Nashville Basin in Tennessee, the rbitrary division between the Eastern and West-rn Highland Rims, is the eastern edge of soil asso-iation D42 in Sumner County. This boundary erges with the Western Pennyroyal-Limestone rea and the Eastern Pennyroyal boundary in entucky (Bailey and Winsor 1964; Soil Conserv. erv. 1975).

limate

The region has a temperate climate characterized long, moderately hot summers and short, mild winters. According to Thornthwaite's (1931) classification of climate, it is humid mesothermal. Daily and seasonal weather is controlled largely by alternating cold, dry continental air masses from Canada and warm, moist air from the Gulf of Mexico. During the summer, complete exchanges of air masses are few, and tropical maritime air masses persist for extended periods. Tables 1 and 2 show average monthly and annual precipitation and temperature values, average frost-free periods, and elevation above sea level for three stations in Tennessee and one in Kentucky (fig. 2).

Mean temperature for the region is about 58° F. The average date of last freeze is early to mid April and the average date of first freeze is mid to late October. Therefore, most of the region has an average frost-free period of 190 to 205 days. The temperature often falls below freezing at night in December, January, and February. The ground freezes to a depth of 2 to 6 inches several times during the average winter season and commonly remains frozen for 2 to 12 days. Air temperature does not appear to vary much across the region. However, local temperature may vary considerably because of elevation, aspect, and cloud cover.

Southerly winds prevail from May to September and northerly ones from November to March; average velocity ranges from 5 to 10 mph. Severe winds are infrequent, and most are associated with summer thundershowers.

Annual precipitation averages about 50 inches and ordinarily is fairly well distributed throughout the year. Rainfall decreases slightly south to north. Precipitation is greatest from December through

ble 1.—*Average monthly and annual precipitation in inches for four weather stations on the Western Highland Rim and Pennyroyal*[1]

Station and county	Years of record	Elevation Ft	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
aynesboro Wayne, TN	90	750	5.5	5.8	5.7	5.4	4.2	4.0	4.0	3.8	3.2	2.7	4.8	5.4	54.6
ckson Dickson, TN	82	814	5.1	4.8	5.5	4.6	4.2	3.6	4.1	4.0	2.8	2.5	4.0	4.8	50.1
ringfield Robertson, TN	42	745	4.8	4.6	4.8	4.3	4.2	3.4	3.7	3.2	2.8	2.7	4.0	4.5	47.0
wling Green Warren, KY	93	535	4.6	4.4	5.5	4.2	4.2	4.2	4.1	3.0	3.0	2.4	4.0	4.4	48.1

[1] S. Department of Commerce (1974a, 1974b).

Table 2.—*Average monthly and annual temperature in °F and length of warm period for four weather stations on the Western Highland Rim and Pennyroyal*[1]

Station and county	Years of record	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Warm period days[2]
Waynesboro Wayne, TN	89	38	40	48	59	66	74	77	76	70	58	47	39	58	189
Dickson Dickson, TN	78	38	41	49	60	68	76	79	78	71	61	49	40	59	193
Springfield Robertson, TN	31	36	39	47	59	67	75	78	77	71	60	48	39	58	206
Bowling Green Warren, KY	93	36	38	46	58	67	75	78	77	70	59	46	38	57	191

[1] U.S. Department of Commerce (1974a, 1974b).

[2] Mean period from last 32° F to first 32° F (U.S. Department of Agriculture 1941).

March. Least precipitation is from August through October. Short periods of very wet or very dry weather are common. Thunderstorms with high intensity rainfall, occasionally hail, occur on over 50 days each year, mostly in the summer months. Snowfall seldom exceeds a few inches and melts in a few days. Soils are wettest from December to April and driest from July to October. Tree growth is commonly retarded for periods of a few to several days up to six times each growing season.

Soil dryness during the growing season can also be shown by "frequency of drought days" data (Knetsch and Smallshaw 1958). A drought day is a day when precipitation and evapotranspiration data indicate that soil moisture content is below the wilting point. Drought days are most likely in August when the probability of 10 drought days per month is 50 percent. The next highest probability of drought days is in July and September when the probability of 10 drought days is about 34 percent.

Geology, Topography, and Soils

In general, the Western Highland Rim and Pennyroyal region is underlain by a series of Mississippian limestones of varying coarseness, purity, and solubility. The boundary between the Rim and the Upper Coastal Plain is indistinct and irregular because unconsolidated Cretaceous sands and gravels cap broad uplands in practically all parts of the Rim (Hajek and others 1975, Soil Conserv. Serv. 1975, Elder and Springer 1978). A thin layer (4 feet or less) of loess overlies parts of both the Rim and Coastal Plain. Alluvial deposits of Quaternary age occur along the Tennessee, Cumberland, Harpeth, Duck, Buffalo, Elk, Green, and Barren Rivers. In the transition from the Rim to the Outer Nashville Basin, phosphatic limestones and shales of Devonian, Silurian, and Ordovician age are exposed.

Topography of the region ranges from gentle to rugged and complex. Slope varies from nearly level to very steep. On the Rim west of the Nashville Basin a dendritic drainage pattern indicates that dissection is about mature. Ridgetops are about 800 to 1,000 feet above sea level, and local relief is 200 to 300 feet. In places, remnants of the once broad undulating plateau remain. Here ridges extend for 0.5 mile or more and relief is 50 feet or less. In northern Alabama the Rim surface ranges from 500 to 800 feet above sea level.

In the northern tier of counties in Tennessee and the Pennyroyal of Kentucky, topography gradually becomes less rugged. Uplands consist of broad rolling to gently sloping interstream areas dotted with sinkholes and depressions. In this karst area, permanent streams are few and drainage is mostly underground in an extensive system of caverns.

In the more rugged section of the Western Highland Rim, upland soils are derived from loess, cherty limestone, noncherty limestone, and Coastal Plain sediments. Soils are generally well drained and low to moderate in fertility. However, fragipans restrict root growth and impede internal drainage in some soils. Typical upland soils are ountview, Dickson, Bodine, and Baxter. About 8 percent of this rugged area is forested ranging rom 40 percent in Giles County to 80 percent in Vayne County, Tennessee (Hedlund and Earles 971).

In the smoother section of the Rim and Pennyoyal, upland soils developed in loess and thick unerlying layers of clay weathered from relatively hert-free limestone. Soils are generally well rained with moderately high fertility. Common oils are Pembroke, Crider, Baxter, and Nicholson. his area is well suited to agriculture, but forests ccupy about 38 percent of the area ranging from 5 percent in Simpson to 50 percent in Lyon ounty, Kentucky (Hedlund and Earles 1971, 1973; ingsley and Powell 1978).

Fertile soils that developed on floodplains and w terraces along the major rivers have been covred by the lakes constructed by the Tennessee Valy Authority and the Corps of Engineers. High rraces are seldom flooded, and soils are deep and oderately high in fertility. Common soils are Pickick, Armour, Huntington, Arrington, Beason, ewark, and Dunning. These floodplains and terces are well suited to agriculture. Seasonal wetess limits their use in places. The normal level of entucky Lake and Lake Barkley is 359 feet above a level, Pickwick Lake is 414 feet, Wilson Lake is 08 feet, and Wheeler Lake is 556 feet.

In the transition to the Outer Nashville Basin, pography is complex, consisting of knobs and narw, meandering hills that are erosional remnants f the Mississippian plateau. Bodine soils occur on e hilltops and steep upper slopes while Sulphura, ellrose, and Mimosa constitute the common seuence of soils on slopes into the Outer Basin. aury, Braxton, and Harpeth soils are common on uter Basin ridges and valleys.

Gradient, aspect, slope length, and soil moisture re important in the delineation of landtypes deribed later. Slope and topography affect the rate nd amount of both surface runoff and subsurface ovement of soil water. Soil loss by erosion ineases as gradient and length of slope increase. lthough surface runoff is rare under forested contions, it is important during road construction, gging, and other forest management operations. oils on steep slopes are often shallower than soils n more nearly level terrain. Deposition of sedients on gentle terrain by surface runoff is greatest low the longer and steeper slopes.

Generally, the steeper the gradient and the nger the slope, the greater is the subsurface flow of soil water downslope. As a consequence, plants on lower slopes grow for longer periods without moisture stress. Subsurface flow may result in excessively wet soil with poor aeration at the base of long slopes. Areas of karst topography are an exception. Here, soil water percolates deep into the porous limestone instead of moving downslope in the soil.

Aspect affects air and soil temperatures. Soil temperatures are lower on north-facing than on south-facing slopes. Because soils on north-facing slopes retain moisture longer during the growing season, both rate of tree growth and species composition are better on north-facing than on south-facing slopes.

In soil taxonomy, temperature regime is one of several differentiae used to place soils into a subgroup having similar physical and chemical properties (Soil Survey Staff 1975). For the Western Highland Rim and Pennyroyal, two soil temperature classes are recognized – mesic and thermic. Temperature regime of mesic soils ranges from 8° to 15° C (47° to 59° F), and the regime of thermic soils ranges from 15° to 22° C (59° to 72° F). Both classes also have a difference of 5° C (9° F) or more between mean summer and mean winter soil temperature. All temperature measurements are at a depth of 50 cm or at a lithic or paralithic contact, whichever is shallower.

Accordingly, all soils mapped in the Alabama portion of the Western Highland Rim are thermic. In Tennessee, the 15° C isotherm passes through Sumner and Robertson Counties and nearly all Western Highland Rim soils are thermic. The Western Pennyroyal-Limestone Area in Kentucky is a transition zone because both mesic and thermic soils are recognized.

SUBREGIONS AND LANDTYPE ASSOCIATIONS

I have divided the Western Highland Rim and Pennyroyal region into four subregions: 1) Highland Rim plateau, 2) Highland Rim-Nashville Basin transition, 3) Karst plain, and 4) Major river bottoms (fig. 2). Each subregion was further divided into two to four landtype associations (LTA) that correspond closely to soil associations shown on general soil maps for Alabama, Kentucky, and Tennessee (Hajek and others 1975; Soil Conserv. Serv. 1975; Elder and Springer 1978; Edwards and others 1974) (table 3). A description of these landtype associations follows.

Subregion 1: Highland Rim Plateau

Landtype Association-A: Strongly Dissected Plateau.—This landtype association corresponds to soil associations D11 (Bodine-Mountview-Dickson) and D12 (Bodine-Talbott) in Tennessee and extends south into northern Alabama where it merges mostly with soil association 11 (Minvale-Fullerton). Portions of LTA-A extend west of the Tennessee River in Tennessee.

Also included in LTA-A is soil association D31 (Brandon-Lax) in Lewis, Dickson, and Humphreys Counties, Tennessee and soil association C23 (Shubuta-Silverton-Bodine-Dulac) in southern Wayne County, Tennessee. I included association C23 to improve coincidence between the Highland Rim and Upper Coastal Plain physiographic provinces at the Tennessee-Alabama State boundary. A small area of soil association D31 on Tennessee Ridge in northwest Stewart County, Tennessee, was merged with an extensive area of soil association B3 (Brandon-Loring-Saffell) in Trigg County, Kentucky, and placed in the Upper Coastal Plain physiographic province.

Landtype association-A consists of narrow winding to moderately broad undulating ridges flanked by steep side slopes. Valleys in the upper reaches intermittent streams are narrow and V-shaped, b gradually become U-shaped with bottoms as wi as 250 to 500 feet before merging with major riv bottoms (Subregion 4).

Hilly and steep parts of LTA-A have well-drain to excessively drained, cherty, loamy and clay soils derived from cherty limestone. Undulati parts have well drained to moderately well drain silty soils developed in 2 to 4 feet of loess over clay residuum from cherty limestone or over gravel mostly unconsolidated, Coastal Plain sediments.

Most of LTA-A is forested. Only the smooth ridges have been cleared for agriculture and so of these have been abandoned. Eleven landtyp are recognized: 1-11.

Landtype Association-B: Moderately Dissect Plateau.—This LTA corresponds to soil associati D21 (Baxter [Fullerton]-Mountview-Dickson) Tennessee and soil association D2 (Baxter-Crid in Kentucky.

Landtype association-B consists of broa rounded hills interspersed with narrow, windi ridges flanked by moderately steep to steep si slopes. Near the heads of intermittent streams, v leys are V-shaped, but gradually become U-shap with bottoms as wide as 500 to 800 feet before me ing with major river bottoms (Subregion 4).

Hilly and rolling parts of LTA-B have mostly w drained, cherty, and clayey soils derived from lin

Table 3.—*Subregions and landtype associations of the Western Highland Rim and Pennyroyal region*

Subregion	Landtype association
1. Highland Rim plateau	A. Strongly dissected plateau B. Moderately dissected plateau C. Weakly dissected plateau-gray soils D. Weakly dissected plateau-red soils
2. Highland Rim-Nashville Basin transition	E. Knobs F. Outer Basin
3. Karst plain	G. Weakly dissected plain H. Moderately dissected plain I. Slump area
4. Major river bottoms	J. Tennessee River bottom K. Buffalo River bottom L. Cumberland, Harpeth, Duck, and Elk River bottoms M. Green and Barren River bottoms

tone residuum, and the smoother parts have well rained and moderately well drained silty soils de-eloped in 2 to 3 feet of loess over limestone resid-um.

The smoother, broader ridges and mild slopes are n agriculture. Steep or wet areas are in woodland. Nine landtypes are recognized: 1-6 and 9-11.

Landtype Association-C: Weakly Dissected Pla-eau-Gray Soils.—This LTA corresponds to soil as-ociation D32 (Dickson-Mountview-Guthrie) in ennessee and soil association 7 (Dickson-Fuller-on) in Alabama. Soil association D32 was extended nto Kentucky in southeastern Trigg and south-estern Christian Counties, although it is not rec-gnized on the Kentucky general soil map.

Landtype association-C consists of broad, nearly evel to undulating ridges with some depressions nd sinkholes. These uplands are dissected by a eak to moderately well developed dendritic drain-ge system. Bottoms of intermittent streams are aucer-shaped with little gradient. Many intermit-ent streams empty into sinkholes. Bottoms of per-nanent streams are U-shaped. Short moderately teep slopes surround most sinkholes and separate ottoms of permanent streams from broad ridges.

The silty and cherty soils are well drained to oorly drained and derived from 2 to 6 feet of loess verlying old alluvium or from clayey residuum rom limestone.

Most of LTA-C has been cleared and is used for rops and pasture. Steep slopes and wet areas are in oodland. Nine landtypes are recognized: 5, 6, 9, 0, 12, 14, 15, 27, and 28.

Landtype Association-D: Weakly Dissected Pla-eau-Red Soils.—This LTA corresponds to soil as-ociation D51 (Waynesboro-Decatur-Bewleyville-urtistown) in Tennessee and soil association 5 Decatur-Dewey) in Alabama. It is limited to three olated areas—two in Lauderdale County, Ala-ama, and one in Lawrence County, Tennessee. his LTA is extensive in the Eastern Highland Rim egion of northern Alabama and central Tennessee.

Landtype association-D consists of broad, gently oping ridges bounded by generally short, sloping nd moderately steep side slopes. Uplands are pit-ed with sinkholes and depressions. Many shallow ntermittent drainages and a few permanent reams comprise the weakly developed dendritic rainage pattern.

The mostly well drained and clayey soils are de-ved from a layer of loess overlying old alluvium or clayey residuum from moderately high-grade limestone.

Most of the LTA-D has been cleared for crops and pasture. Steeper slopes and poorly drained areas are in woodland. Nine landtypes are recognized: 5, 6, 9, 10, 13-15, 27, and 28.

Subregion 2: Highland Rim-Nashville Basin Transition

Landtype Association-E: Knobs.—This LTA corresponds to soil association E11 (Dellrose-Mimosa-Bodine) in Tennessee.

Landtype association-E consists of a nearly continuous belt of high cherty ridges and knobs with steep side slopes, as much as 1,000 feet long, and narrow valleys. Ridges are remnants of the Highland Rim plateau and are capped with Ft. Payne chert. Valleys are mainly V-shaped at the heads, but become U-shaped downstream, and do not exceed ¼ mile in width; most are ⅛ mile or less. Elevation ranges from 900 to 1,200 feet above sea level and relief is 180 to 300 feet. This strongly dissected belt ranges in width from about 2 miles in Davidson County in north central Tennessee to about 25 miles in the Elk River basin in south central Tennessee and northern Alabama.

The area is hilly to steep with deep, well drained loamy and clayey soils that are mostly cherty. They formed in residuum from cherty limestone, shale, and phosphatic limestone, and in colluvium. Thin layers of Chattanooga and Maury shales and the lower shaly facies of Ft. Payne chert are exposed in places on steep slopes.

Agriculture is limited by slope steepness, high chert content, or rockiness. Considerable cleared acreage is reverting to woodland. Seven landtypes are recognized: 1, 11, 12, and 16–19.

Landtype Association-F: Outer Basin.—This LTA corresponds to that portion of soil association E31 (Maury-Braxton-Harpeth) in Giles County, Tennessee which is surrounded by LTA-E.

Landtype association-F consists of low broad uplands and hills and the associated bottomlands along Richland Creek and its larger tributaries. Soils are derived from limestone, which is moderate to high in phosphate, alluvium, and loess in some places. Soils are deep, well drained, and predominantly clayey with some silty ones. Topography is undulating to rolling; few slopes exceed 25 percent. Relief is about 200 feet and the highest elevations are about 800 feet above sea level.

Most of LTA-F is in crops or pasture. Only the steepest slopes and shallower soils are in woodland. Six landtypes are recognized: 11 and 18–22.

Subregion 3: Karst Plain

Landtype Association-G: Weakly Dissected Karst Plain.—This LTA corresponds to soil association D1 (Crider-Baxter) and D3 (Fredonia-Pembroke) in Kentucky and D41 (Pembroke-Crider) and D42 (Baxter-Bewleyville-Pembroke) in Tennessee.

Landtype association-G consists of mostly deep, well drained intermingled clayey and silty soils some of which are cherty. They developed in thin loess, alluvium, and clayey residuum from moderately high-grade limestone situated on an undulating to rolling karst plain. This broad wavy plain is pitted with sinkholes and shallow depressions which connect in underground drainageways. Surface drainages are shallow and meandering; there are few permanent streams. In some areas, particularly in soil association D3, the landscape is slightly more complex, slopes are somewhat steeper, soils are predominantly less than 60 inches thick, and limestone outcrops and escarpments are common. Relief ranges from 30 to 90 feet. Steepest parts are near the Barren and Green Rivers (LTA-M), the Red River, and other major permanent creeks and rivers.

Most of the soils in LTA-G are quite fertile. Over 75 percent of the area is in agriculture. Woodlands usually occur on the steeper and poorly drained parts of the landscape. Twelve landtypes are recognized: 11, 12, and 23–32.

Landtype Association-H: Moderately Dissected Karst Plain.—This LTA corresponds to soil association D4 (Crider-Vertress) in Kentucky.

Landtype association-H consists of deep, moderately well drained and well drained soils formed in thin loess over limestone residuum, and deep well drained soils formed in clayey residuum from limestone and thin bedded shale and siltstone on a rolling upland dissected by many small streams and sinkholes. The surface drainage network is more defined than in LTA-G, although many streams drain into sinks and depressions.

Relief commonly exceeds 100 feet and ranges up to 160 feet in the vicinity of larger streams. Slopes are 200 to 400 feet long.

This LTA is extensively farmed, but woodland are scattered throughout the area. Some abandoned farmland is reverting to woodland. Ten landtypes are recognized: 11, 23, 27, 28, and 31–36.

Landtype Association-I: Slump Area.—This LTA corresponds to soil association D5 (Sonora-Gatt in Hardin, Hart, and Larue Counties, Kentucky is characterized by localized deposits of sandstone, siltstone, shale, and limestone that overlaid the Genevieve limestone (dominant baserock of the Pennyroyal) and slumped into sinkholes and caverns during an earlier cycle of karst erosion. places these deposits range up to 210 feet thick, and in other places they are shallow and mixed with residual soil materials. A thin capping of loess occurs in some parts of the area.

Landtype Association-I consists of mostly well drained soils formed in loamy, unconsolidated residuum of sandstone, siltstone, and shale origin. Topography is undulating to rolling and hilly with a dendritic drainage pattern. Relief is commonly about 60 feet but may range up to 100 feet in the vicinity of larger streams.

This LTA is used mainly for farming. Small woodlots are common and there are a few large wood tracts. Some abandoned fields are reverting to woodland. Eight landtypes are recognized: 11, 32, and 37–41.

Subregion 4: Major River Bottoms

Landtype Association-J: Tennessee River Bottom.—This LTA corresponds to soil association A4 (Wolftever-Egam-Beason-Lindside) along the Tennessee River in Hardin, northwestern Wayne, and southeastern Perry Counties, Tennessee.

Landtype association-J consists mostly of moderately well drained and somewhat poorly drained clayey soils, and some silty soils that formed in mixed alluvium on nearly level to rolling terraces and floodplains.

Most of LTA-J has been cleared for agriculture. Only the steeper and wetter areas are in woodland. Two landtypes are recognized: 42 and 43.

Landtype Association-K: Buffalo River Bottom.—This LTA corresponds to soil association A42 (Ennis-Humphreys-Lobelville) along the Buffalo River in west central Tennessee.

Landtype association-K consists mostly of deep, well drained and moderately well drained cherty and loamy soils formed in alluvium on level to moderately steep footslopes, terraces, and floodplains. The entire watershed of the Buffalo River drai

Western Highland Rim plateau. Alluvium is shed from soils derived from cherty low-grade estone and a capping of loess.

About 60 percent of LTA-K is in agriculture. The nainder is woodland or abandoned fields. The er lying portions are frequently flooded, partic-rly in late winter and spring. Two landtypes are ognized: 44 and 45.

andtype Association-L: Cumberland, Harpeth, ck, and Elk River Bottoms.—This LTA corre-nds to soil association A43 (Arrington-Lindell-am-Armour) along the Cumberland, Harpeth, ck, and Elk Rivers in Tennessee and northern bama.

andtype association-L consists mostly of well ined and moderately well drained silty soils and w clayey soils on footslopes, terraces, and flood-ins of rivers which originate in or flow through Nashville Basin. Most soils are moderate to h in phosphate. On the floodplains, coarse-tex-ed and better drained soils are on the highest as adjacent to the rivers and as distance from rivers increases, the soils become progressively re clayey and less well drained.

luctuating water tables and occasional flooding it the use and affect the management of this A. Except for a few wooded tracts on poorly ined soils, all of this LTA has been cleared for iculture. Two landtypes are recognized: 46 and

andtype Association-M: Green and Barren er Bottoms.—Bottoms in the middle and upper ches of major rivers were not delineated on the eral soil map of Kentucky. However, these two er bottoms are similar to LTA's-J, K, and L and uld be recognized, although they only traverse Western Pennyroyal-Limestone Area for short tances. The upper portion of these two rivers in part of the Eastern Highland Rim and Pen-oyal region in Kentucky and northern Tennes-

andtype Association-M consists of well drained somewhat poorly drained silty soils formed in ked old alluvium on gently sloping to strongly ping terraces, and well drained to very poorly ined soils formed in young mixed alluvium on el to gently sloping floodplains. There is some dence of loess in the alluvium.

roductivity and management interpretations similar to LTA-L except soils in LTA-M are stly in the mesic temperature regime and nei-r the Barren or Green River watersheds contain ks with high contents of phosphate.

Seasonal high water tables and occasional flooding limit the use and affect the management of this LTA. Most of LTA-L has been cleared for agriculture. Two landtypes are recognized: 48 and 49.

LANDTYPES

I have divided each landtype association into landtypes, which are the smallest unit of the landscape recognized in this classification system. Wertz and Arnold (1975) describe landtypes as visually identifiable areas each being reasonably uniform in soils and productivity and having resulted from similar climatic and geological processes.

The Western Highland Rim and Pennyroyal region has 49 landtypes distributed among 4 subregions and 13 landtype associations (table 4). Some are common to as many as seven landtype associations while others are characteristic of only one association. Figures 3 to 7 depict how these landtypes occur on the landscape in landtype associations A to I. Only one major river bottom (LTA-J) is shown (fig. 3) because bottoms have simple landscapes with landtypes defined entirely on the basis of soil drainage.

Letters in the upper right-hand corner of each landtype description identify the landtype association(s) in which each landtype occurs.

Aspect distinguishes some landtypes and is recorded as either north or south. North aspects include all azimuths from 315° (northwest) to 135° (southeast). The remainder of the azimuth circle represents south aspects.

Each landtype is described in terms of nine elements. The **Geographic Setting** provides an overall description of the landtype, specifying both where it occurs on the landscape and its relation to other landtypes. Some key soil properties such as depth and texture are described in general terms. Texture refers to the upper part (about 2 feet) of the subsoil. Slope is classified in accordance with SCS standards (Soil Survey Staff 1951).

Slope Classes and Corresponding Percent of Slope

Slope percent	Class
0–2	Level or nearly level
2–6	Gently sloping
6–10	Sloping
10–15	Strongly sloping
15–25	Moderately steep
25–45	Steep
45 +	Very steep

The most prevalent soil series are listed under **Dominant Soils.** These series names reflect the most recent designations in soil classification and link this site classification system with county soil surveys published by the SCS. Users who wish more detailed information can refer to soil series descriptions issued by the SCS.

The kind of **Bedrock** or **Soil Parent Material** and **Depth to Bedrock** are listed next. **Texture** of the topsoil (upper 5 to 8 inches) is described in terms of the 12 conventional classes, which are based on percentages of sand, silt, and clay-size particles. Textural modifiers, such as cherty and gravelly, are used where the amount of rock fragments is significant (Soil Survey Staff 1951).

The seven conventional **Soil Drainage** classes are: *very poorly drained, poorly drained, somewhat poorly drained, moderately well drained, well drained, somewhat excessively drained,* and *excessively drained* (Soil Survey Staff 1951). **Relative Soil Water Supply** of each landtype is rated in five classes: *very low, low, medium, high,* and *very hig* This qualitative rating is based on the availab water holding capacity of the dominant soils (function of soil thickness and texture includin rock fragments), but allowances are made for th influence of soil drainage, topographic position, an aspect.

Soil Fertility is described as: *very low, low, mo erately low, moderate, moderately high, high,* *very high.* Some soils (Bodine, Brandon, Dickso and Mountview) are fairly acid and derived fro rocks with few weatherable minerals while othe (Braxton, Crider, Decatur, and Pembroke) are les acid and contain more weatherable minerals. Co sequently, fertility of Western Highland Rim an Pennyroyal soils varies widely (Edwards and othe 1974, Francis and Loftus 1977).

The most common woody species in approximat order of abundance are listed under **Vegetatio** Some distinctive herbaceous species are include Species nomenclature follows Little (1979) and Fe

Table 4.—*Summary of landtypes and their occurrence by subregions and landtype associations*

Landtype number and name by subregion	Landtype association[1]
Highland Rim Plateau	
1. Narrow ridges and convex upper slopes.	A,B
2. Broad undulating Coastal Plain uplands.	A,B
3. Broad ridges—north aspect.	A,B
4. Broad ridges—south aspect.	A,B
5. Cherty north slopes.	A,B,C,D
6. Cherty south slopes.	A,B,C,D
7. Shaly north slopes.	A
8. Shaly south slopes.	A
9. Footslopes, terraces, streambottoms, and upland depressions with good drainage.	A,B,C,D
10. Terraces, streambottoms, and upland depressions with poor drainage.	A,B,C,D
11. Limestone rockland and shallow soils.	A,B
12. Broad silty uplands.	C
13. Broad undulating uplands.	D
14. Broad ridges—north aspect.	C,D
15. Broad ridges—south aspect.	C,D
27. Upland flats, depressions, and sinkholes with good drainage.	C,D
28. Upland flats, depressions, and sinkholes with poor drainage.	C,D
Highland Rim-Nashville Basin Transition	
1. Narrow ridges and convex upper slopes.	E
11. Limestone rockland and shallow soils.	E,F
12. Broad silty uplands.	E
16. North slopes.	E
17. South slopes.	E
18. Footslopes, terraces, and streambottoms with good drainage.	E,F
19. Terraces and streambottoms with poor drainage.	E,F
20. Low broad ridges.	F
21. North slopes and narrow ridges.	F
22. South slopes and narrow ridges.	F

Table 4.—*Summary of landtypes and their occurrence by subregions and landtype associations—Continued*

Landtype number and name by subregion	Landtype association[1]
Karst Plain	
11. Limestone rockland and shallow soils.	G,H,I
12. Broad silty uplands.	G
23. Broad undulating uplands.	G,H
24. Broad ridges—north aspect.	G
25. Broad ridges—south aspect.	G
26. Narrow limestone ridges and knoblike hills.	G
27. Upland flats, depressions, and sinkholes with good drainage.	G,H
28. Upland flats, depressions, and sinkholes with poor drainage.	G,H
29. North slopes.	G
30. South slopes.	G
31. Terraces and streambottoms with good drainage.	G,H,I
32. Terraces and streambottoms with poor drainage.	G,H,I
33. Broad ridges—north aspect.	H
34. Broad ridges—south aspect.	H
35. North slopes.	H
36. South slopes.	H
37. Broad undulating uplands.	I
38. Broad ridges—north aspect.	I
39. Broad ridges—south aspect.	I
40. North slopes.	I
41. South slopes.	I
Major River Bottoms	
42. Terraces and floodplains with good drainage.	J
43. Terraces and floodplains with poor drainage.	J
44. Footslopes, terraces, and floodplains with good drainage.	K
45. Terraces and floodplains with poor drainage.	K
46. Terraces and floodplains with good drainage.	L
47. Terraces and floodplains with poor drainage.	L
48. Footslopes, terraces, and floodplains with good drainage.	M
49. Terraces and floodplains with poor drainage.	M

[1] See table 3.

ld (1950). Loblolly pine, which occurs on many ndtypes, is native only in northern Alabama and uthern Tennessee but has been planted north of range on converted sites and abandoned fields.

FOREST MANAGEMENT INTERPRETATIONS

ach landtype is evaluated in terms of productiv- t for selected species of trees and species desirabil- t for timber production. Also, each landtype is ed for five soil-related problems that may affect est management.

Productivity

Productivity of commercially valuable species is expressed as site index and as average annual growth in cubic feet per acre. Site index is the total height attained by dominant and codominant trees at some specified age.

For all naturally occurring species, site indices are the means of values from soil survey interpretations for dominant soils in each landtype. Interpretations are issued by the SCS as part of each soil series description. SCS personnel obtained height and age measurements in well-stocked, even-aged, essentially unmanaged stands that had not been damaged excessively by fire, insects, disease, or

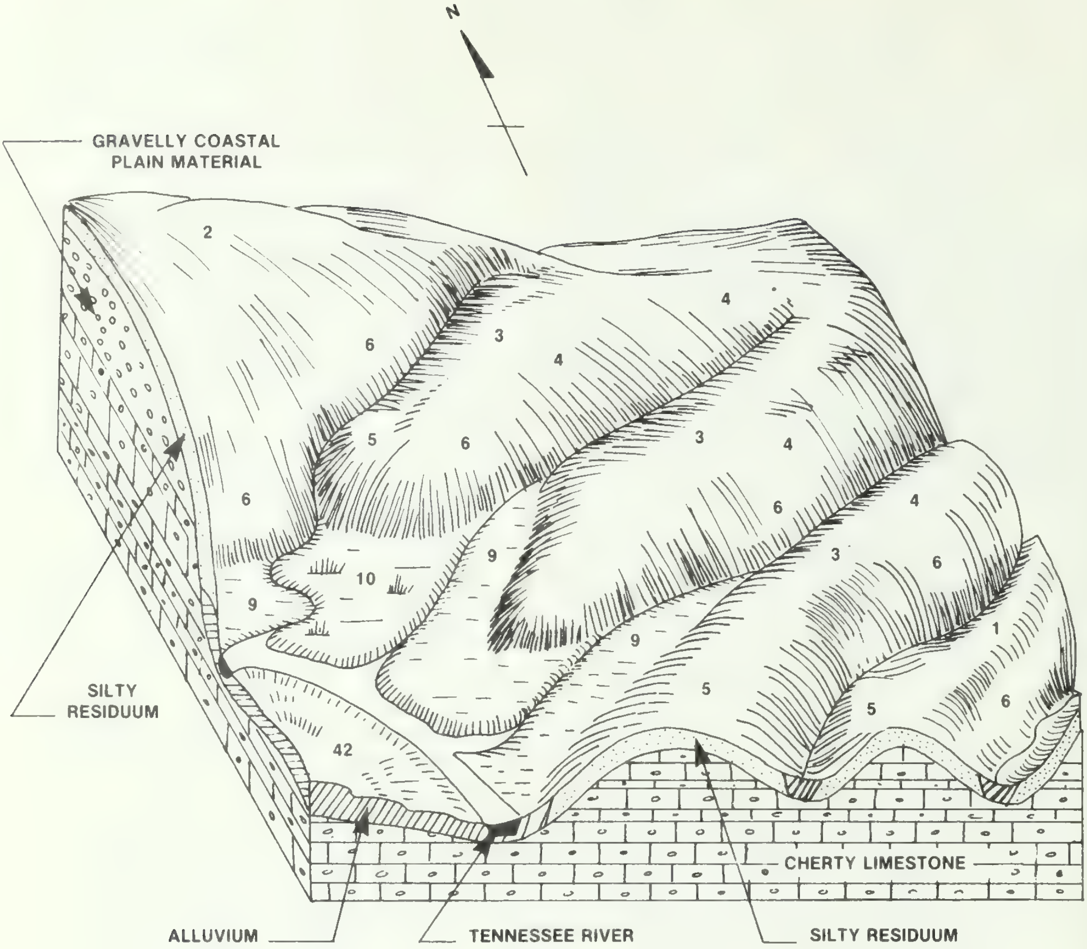

Figure 3.—*Landtypes characteristic of Landtype Associations A and B in Subregion 1 and Landtype Association J in Subregion 4.*

LEGEND

1. Narrow ridges and convex upper slopes.
2. Broad undulating Coastal Plain uplands.
3. Broad ridges—north aspect.
4. Broad ridges—south aspect.
5. Cherty north slopes.
6. Cherty south slopes.
9. Footslopes, terraces, streambottoms, and upland depressions with good drainage.
10. Terraces, streambottoms, and upland depressions with poor drainage.
42. Terraces and floodplains with good drainage.

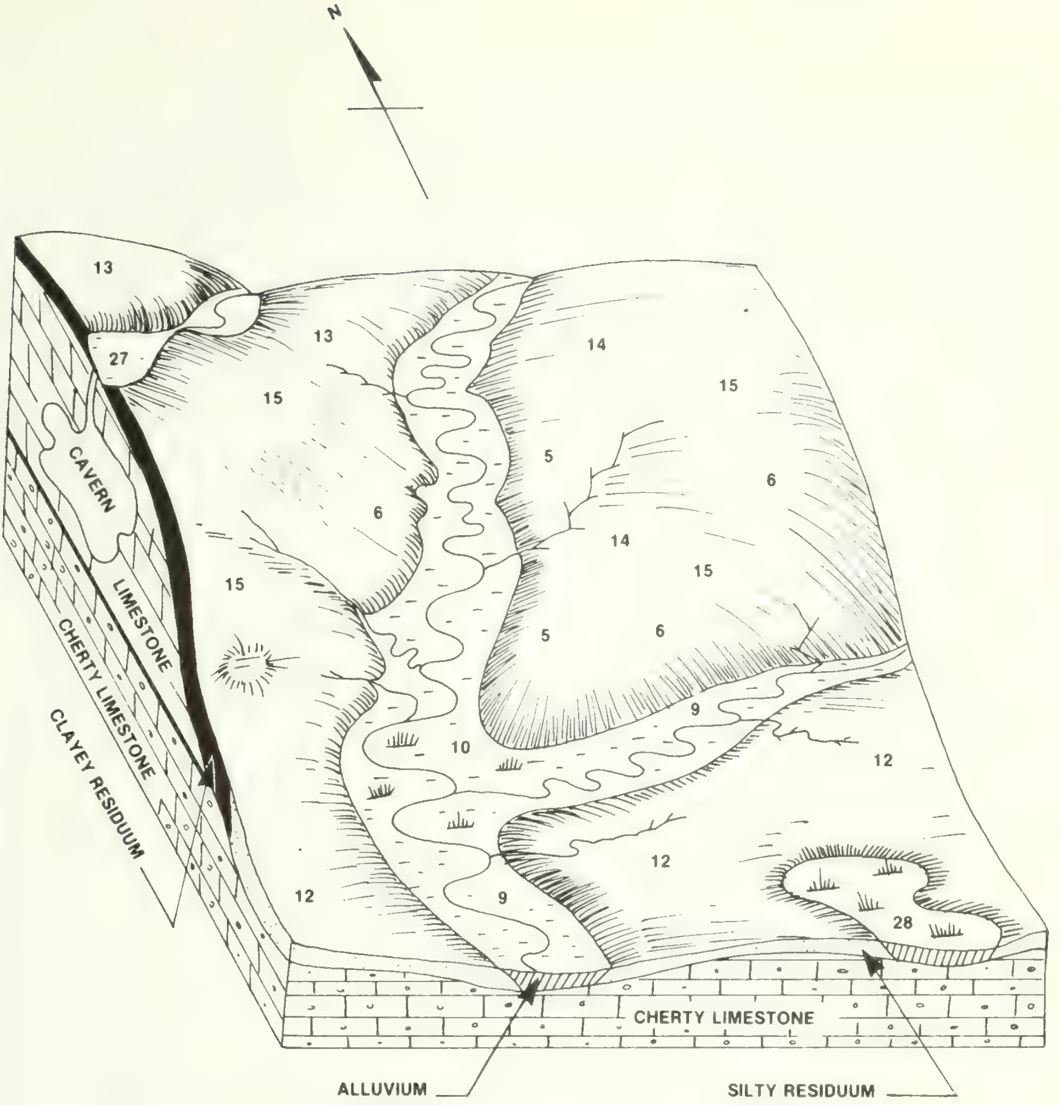

Figure 4.–*Landtypes characteristic of Landtype Associations C (bottom) and D (top) in Subregion 1.*

LEGEND

5. Cherty north slopes.
6. Cherty south slopes.
9. Footslopes, terraces, streambottoms, and upland depressions with good drainage.
10. Terraces, streambottoms, and upland depressions with poor drainage.
12. Broad silty uplands.
13. Broad undulating uplands.
14. Broad ridges—north aspect.
15. Broad ridges—south aspect.
27. Upland flats, depressions, and sinkholes with good drainage.
28. Upland flats, depressions, and sinkholes with poor drainage.

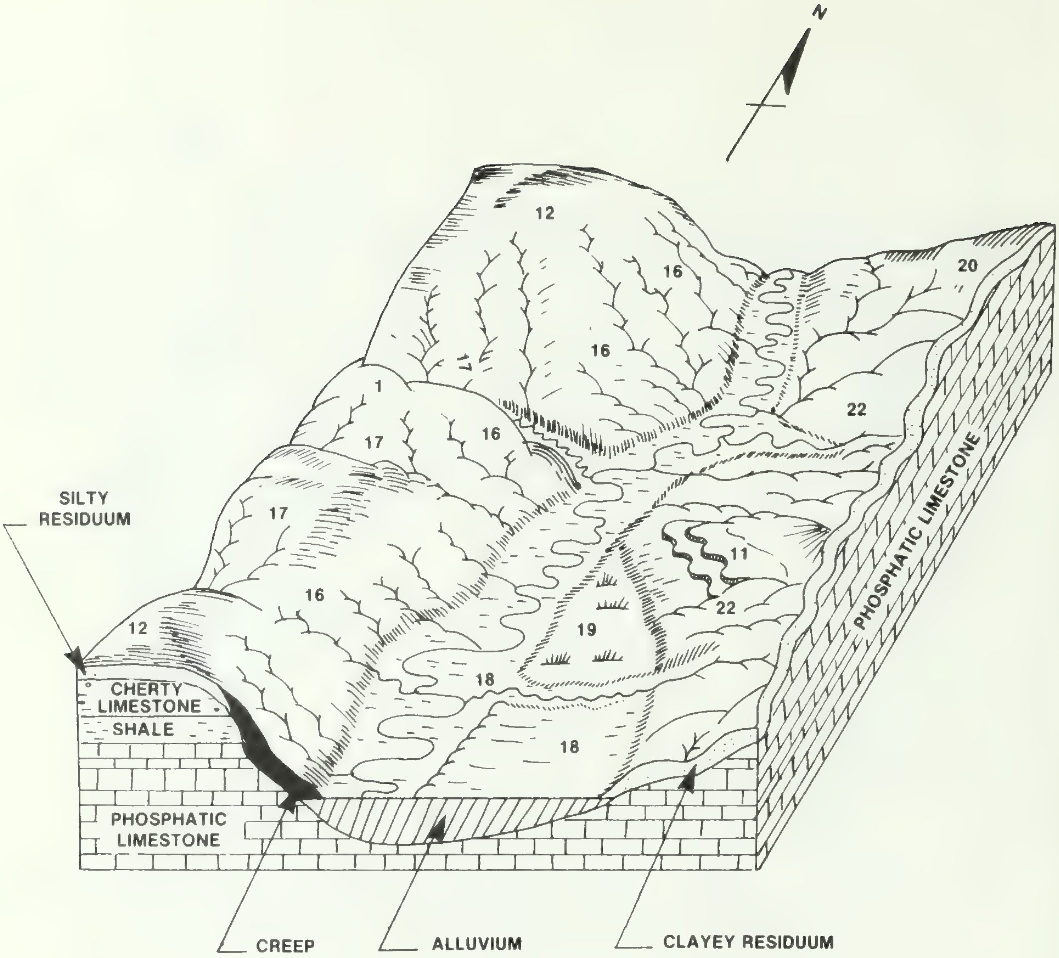

Figure 5.—*Landtypes characteristic of Landtype Associations E (left) and F (right) in Subregion 2. Adapted from figures 4 and 5 in Edwards and others (1974).*

LEGEND

1. Narrow ridges and convex upper slopes.
11. Limestone rockland and shallow soils.
12. Broad silty uplands.
16. North slopes.
17. South slopes.
18. Footslopes, terraces, and streambottoms with good drainage.
19. Terraces and streambottoms with poor drainage.
20. Low broad ridges.
22. South slopes and narrow ridges.

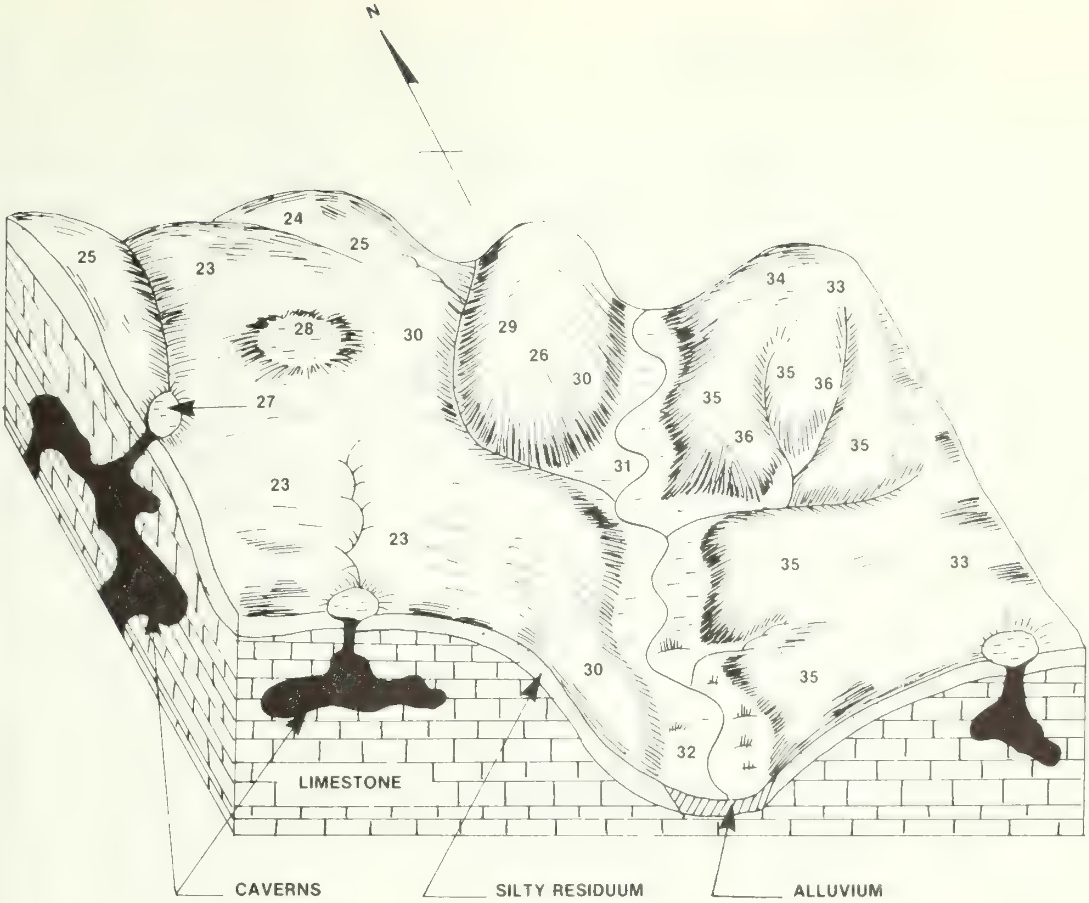

Figure 6.–*Landtypes characteristic of Landtype Associations G (left) and H (right) in Subregion 3.*

LEGEND

23. Broad undulating uplands.
24. Broad ridges–north aspect.
25. Broad ridges–south aspect.
26. Narrow limestone ridges and knoblike hills.
27. Upland flats, depressions, and sinkholes with good drainage.
28. Upland flats, depressions, and sinkholes with poor drainage.
29. North slopes.
30. South slopes.
31. Terraces and streambottoms with good drainage.
32. Terraces and streambottoms with poor drainage.
33. Broad ridges–north aspect.
34. Broad ridges–south aspect.
35. North slopes.
36. South slopes.

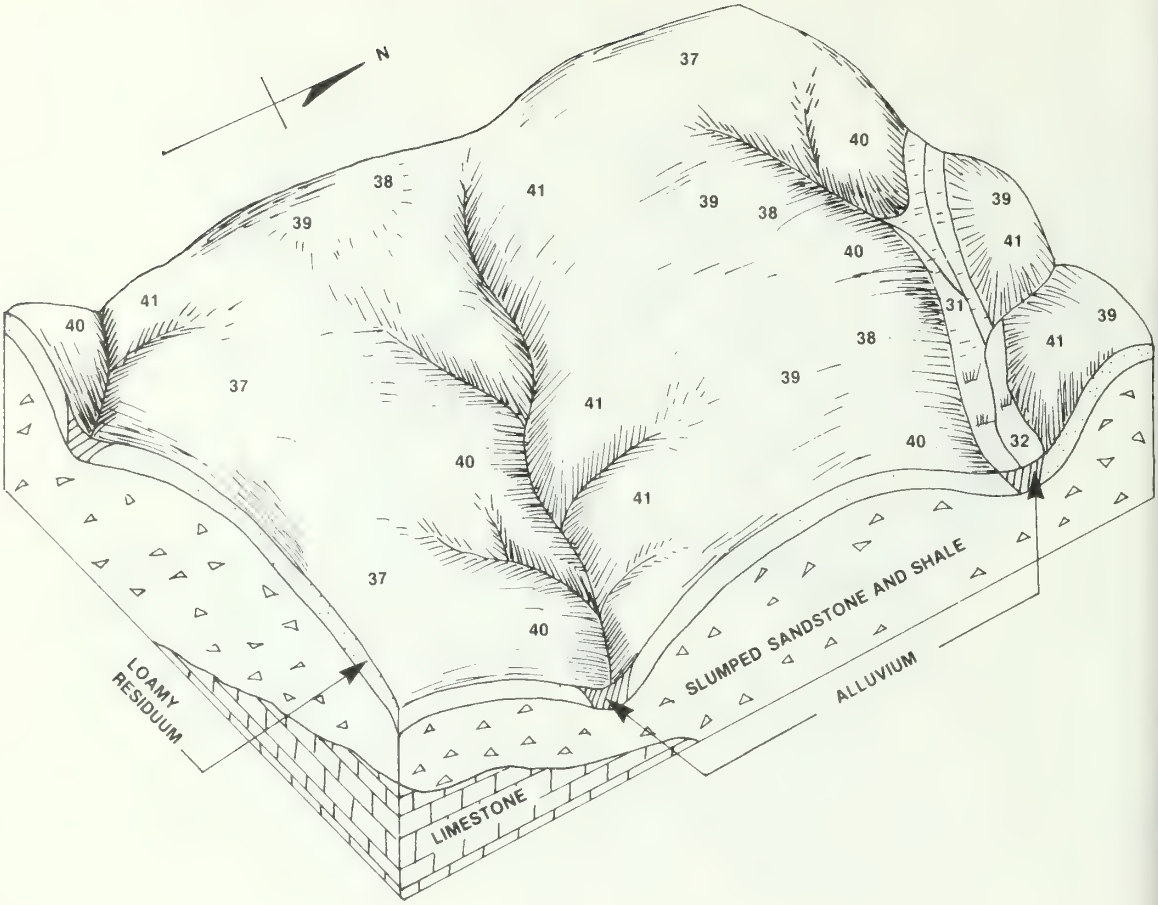

Figure 7.—*Landtypes characteristic of Landtype Association I in Subregion 3. Adapted from figure 4 in Arms and others (1979).*

LEGEND

31. Terraces and streambottoms with good drainage.
32. Terraces and streambottoms with poor drainage.
37. Broad undulating uplands.
38. Broad ridges—north aspect.
39. Broad ridges—south aspect.
40. North slopes.
41. South slopes.

azing. These stands were located on soils repre-
nting, as nearly as possible, the modal concept of
ch soil series. SCS personnel then used index
rves (Beck 1962; Broadfoot 1960, 1963; Broadfoot
d Krinard 1959; Nelson and others 1961; Schnur
37; U.S. Forest Service 1929; and Tennessee Val-
y Authority 1948[2]) to convert height and age data
site indices. Site index curves for all species ex-
pt cottonwood are based on age 50 years; those
r cottonwood on age 30 years.

Site indices, base age 25 years, are given for lob-
lly and shortleaf pines in plantations established
n abandoned fields (Smalley and Bower 1971)
hen data for specific landtypes were available.

In a few cases when no values were available, site
dices, base age 50 years, of important species were
timated. Where they occur in tables 5 to 53 these
timated values are enclosed in parentheses.

Average annual growth expressed in cubic feet
r acre was calculated from available yield tables
McCarthy 1933, Nelson and others 1961, Schnur
37, U.S. Forest Service 1929, and Winters and
sborne 1935). The yield tables represent either
rmal or fully-stocked conditions. Annual growth
tes for all naturally occurring species or forest
pes were averaged over 50 years.

Average annual growth rates for loblolly and
ortleaf pine plantations were derived from Smal-
y and Bailey's (1974a, 1974b) variable-density
eld tables, and a planting density of 1,000 seed-
ngs per acre was assumed. Average growth was
sed on 40 years, the oldest age reported in the
eld tables.

Though our productivity data are the best avail-
le, all site curves and yield tables except those for
antation-grown loblolly and shortleaf pine were
veloped either for geographic areas larger than
t including the Western Highland Rim and Pen-
royal or for areas other than the Western High-
nd Rim and Pennyroyal.

Yields were not expressed in a common mer-
antability standard, so care should be exercised
comparing average annual yields of species both
thin and between landtypes. Footnotes to tables
o 53 specify merchantability standards used.

Management Problems

Plant competition rates the invasion of unwanted plants after openings are made in the canopy. Plant competition is *slight* if unwanted plants do not prevent adequate natural regeneration, interfere with early growth, or restrict normal development of planted or seeded seedlings. Competition is *moderate* if unwanted plants delay establishment and hinder the growth of regenerated seedlings or if they retard the eventual development of a fully stocked stand. Competition is *severe* if unwanted plants prevent adequate restocking without extensive site preparation or special maintenance practices. Competition ratings in tables 5 to 53 represent regional averages, and competition on a given landtype may vary as a result of past land use.

Seedling Mortality is the loss of artificially established tree seedlings as influenced by soils and topographic conditions, assuming that planting is done properly and plant competition is insignificant. Rating is *slight* if expected mortality is 0 to 25 percent, *moderate* if expected mortality is 26 to 50 percent, and *severe* if mortality is more than 50 percent. If the rating is moderate or severe, special preparation of the seedbed and special planting techniques are often necessary to insure a fully stocked stand.

Equipment Limitations are restrictions on the use of conventional wheeled or tracked equipment. Soil and topographic characteristics such as slope, drainage, texture, and rockiness influence equipment limitations, sometimes necessitating the use of different kinds of equipment and methods of operation, or restricting the season when equipment is used. Generally, limitation is *slight* if slope is 20 percent or less and farm machinery can operate efficiently during all seasons. The rating is *moderate* if slope is 20 to 30 percent, limits the use of ordinary farm machinery, and requires track-type equipment; or if soil wetness prevents the use of logging vehicles for 2 to 6 months in a year. The rating is *severe* if slope exceeds 30 percent, making track-type equipment inadequate and requiring power vehicles and other special equipment; or if wetness prevents use of vehicles for 6 months or more in a year.

Erosion Hazard is the degree of potential soil erosion that can occur during and after forest management operations that expose soil along roads,

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e index curves for eastern redcedar based on data from 271
ts throughout the Tennessee River Valley.

skid trails, fire lanes, and landing areas. The ratings assume that the forest is well managed and is protected from fire and grazing. Soil and topographic characteristics considered in rating hazard of erosion include slope, infiltration, permeability, water holding capacity, and resistance to detachment of soil particles by rainfall and runoff. *Slight* indicates that no special measures are needed, *moderate* indicates that some attention needs to be given to erosion control, and *severe* indicates that intensive erosion-control measures are needed.

Windthrow Hazard measures how soils affect root development and how firmly soils hold trees. The hazard is *slight* if rooting depth is more than 20 inches and trees withstand most winds, *moderate* if effective rooting depth is 10 to 20 inches and some trees are blown down during excessive soil wetness and strong winds, and *severe* if effective rooting depth is 10 inches or less and trees will not stand alone in strong winds.

Species Desirability

Three categories are used for rating **Species Desirability** of species that commonly occur on each landtype. *Most Desirable* species are those that have potential for fast growth, high value, or both. *Acceptable* species are those with moderate growth rate or value. *Least Desirable* species are those with slow growth, poor quality, or both. These ratings represent the average situation for the region. The presence or absence of local markets could result in a species being assigned to another category.

USING THE SYSTEM

This guide will allow professional foresters, forest landowners, landuse specialists, forest researchers, and other resource professionals to make onsite determinations of site productivity and will provide a site-dependent framework for forest management planning and forest research.

To make onsite determinations of productiv on a particular tract of land the user must fi determine the subregion and landtype associati in which the tract of land occurs by referring table 3 and fig. 2. Landtypes common to each lar type association are shown in table 4. Landty descriptions and landscape drawings (figs. 3 to will enable the user to identify specific landtyp Information about productivity, severity of ma agement problems, and species desirability is sho on pages facing the landtype descriptions (table to 53).

This site classification system provides a sou biological basis for forest management planning cause it recognizes inherent site differences a soil-related hazards. When the system is adopt landtypes become the basic unit of manageme Continuous Forest Inventory or other forest inve tory systems can easily be incorporated into th site classification system to obtain information acreage, stocking, composition, and growth of fo ests by landtypes. Once productivity data are ava able for landtypes on a specific tract, they shou be substituted for the regional values in the app priate tables.

Users should be aware that productivity will va within a landtype. This variation should be handl as a sampling problem dependent on the desi precision of the productivity information. To a quately sample some landtypes, users with existi inventory systems may be required to install n plots or points. Excessive variation in productiv within a landtype may indicate the need to div that landtype into more homogeneous units.

A logical vehicle to transfer this site classificati system into a valuable forest management tool i landtype map (fig. 8), which can be used in phases of management from day-to-day activit to long-range planning. The number and scale maps will depend on size of ownership and h intensively one wishes to manage. Landtypes c be mapped at scales of 1:10,000 to 1:60,000. Ar as small as 2 acres can be recognized on the lar scale maps. Smoothness of the terrain will det mine maximum size. So the U.S. Geological Surv 7½ minute quadrangle sheets (1:24,000) make cellent base maps on which to delineate landtyp Black and white or color aerial photos, particula stereo pairs, can also serve as base maps. A reas able amount of ground checking should be part e mapping process. Owners or managers of large acts should explore the advantages of computer-nerated mapping of landtypes and other physical d biological features of the landscape (Beeman 78).

For forest researchers, this site classification sys-m provides a basis for stratifying study areas. The stem also aids in identifying and isolating problems that need to be researched. For example, it became apparent in compiling site index and growth information that little mensuration data specific to the region are available. Finally, the system provides researchers with a vehicle for quick transfer of research results to the practitioner. Study results can be reported on the basis of their applicability to specific landtypes.

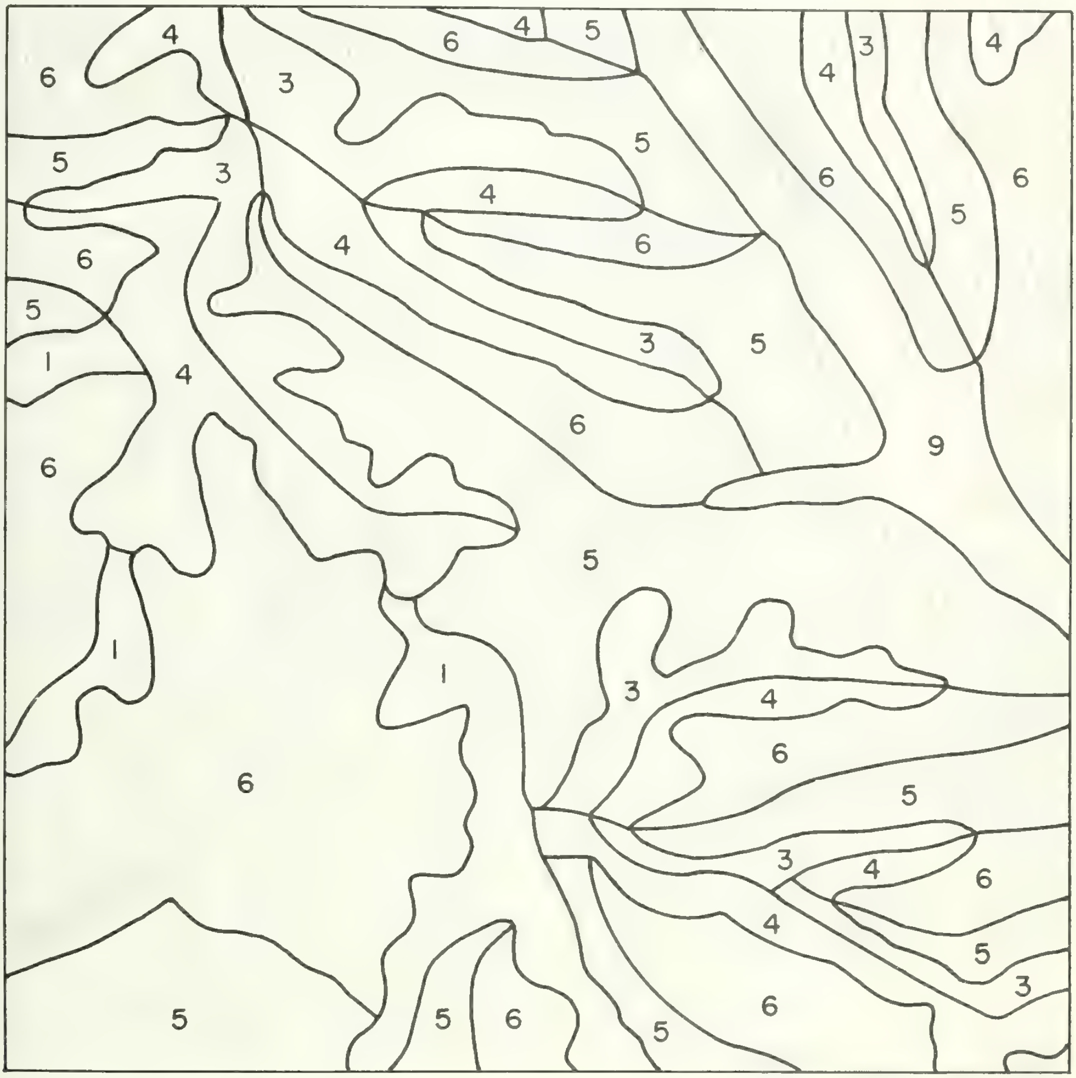

Figure 8.–*A sample landtype map for Landtype Association A (Strongly dissected Highland Rim plateau) in Subregion 1. Map covers a tract of about 700 acres located in the northwest quarter of the Riverside Quadrangle, Lewis County, Tennessee. Scale is 1:12,000.*

Description of Landtype 1: Narrow Ridges and Convex Upper Slopes

Geographic Setting—Deep, cherty soils on undulating to very steep, narrow winding ridgetops, knoblike hills, and adjoining convex upper slopes in Subregions 1 and 2. Slope ranges from 5 to 60 percent. Typically this landtype is no wider than 250 feet. Chert fragments are common on the surface. Twenty to eighty percent of the soil mass may be chert fragments mostly 1 to 4 inches, but some fragments may be 2 feet across.

Dominant Soils—Bodine and Fullerton.

Bedrock—Cherty limestone.

Depth to Bedrock—More than 5 feet.

Texture—Cherty silt loam, cherty loam, or cherty sandy loam.

Soil Drainage—Well drained to somewhat excessively drained.

Relative Soil Water Supply—Low.

Soil Fertility—Moderately low.

Vegetation—Scarlet oak, chestnut oak, post oak, white oak, hickories, southern red oak, loblolly pine, Virginia pine, and shortleaf pine; occasional black oak, blackgum, red maple, yellow-poplar, blackjack oak and eastern redcedar. Dogwood, sourwood, eastern hophornbeam, winged elm, sassafras, huckleberries, and wild plum are common in the understory.

ble 5.—*Forest management interpretations for Landtype 1: Narrow Ridges and Convex Upper Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	65	(50)	95	117
Shortleaf pine	55	(40)	67	84
Virginia pine	55		41	
Eastern redcedar	40		...	
Chestnut oak	55		38	
Scarlet oak	55			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate to severe	Moderate to severe	Moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	White oak	E. hophornbeam
Virginia pine	Chestnut oak	Post oak
	Black oak	Blackjack oak
	S. red oak	Winged elm
	Scarlet oak	Sassafras
	Yellow-poplar	Red maple
		Blackgum
		Dogwood
		Sourwood

Description of Landtype 2:
Broad Undulating Coastal Plain Uplands

Geographic Setting–Moderately deep and deep soils on gently sloping to sloping broad ridges that typically occupy the smoother and higher parts of the landscape in Subregion 1. Slope does not exceed 12 percent, but the area with slope greater than 6 percent is small and aspect is not a dominant site factor. Soils developed in 2 to 4 feet of loess over gravelly, mostly unconsolidated Coastal Plain sediments. Volume of gravel in the C horizon ranges from 20 to 90 percent. Gravel is mostly chert, but some is quartz, and there are cemented layers in places. On steep side slopes below these broad ridges, the Coastal Plain sediments have been truncated and soils developed in the underlying cherty limestone. (See Landtypes 5 and 6.)

Dominant Soils–Brandon and Lax.

Bedrock–Cherty limestone.

Depth to Bedrock–More than 5 feet. Lax soils have a fragipan at depths of 18 to 35 inches.

Texture–Silt loam; gravelly in the lower horizons.

Soil Drainage–Well drained to moderately well drained.

Relative Soil Water Supply–Medium.

Soil Fertility–Moderately low.

Vegetation–White oak, northern red oak, black oak, southern red oak, hickories, scarlet oak, loblolly pine, shortleaf pine, Virginia pine, blackgum, and elms; occasional American beech, chestnut oak, post oak, red maple, sweetgum, and yellow-poplar. Persimmon, dogwood, sassafras, and sourwood are common in the understory.

able 6.—*Forest management interpretations for Landtype 2: Broad Undulating Coastal Plain Uplands. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	80	55	123	133
Shortleaf pine	70	(40)	125	84
Virginia pine	70		92	
N. red oak	70		57	
Yellow-poplar	90		90	
Sweetgum	85		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Slight	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	American beech
Loblolly pine	Chestnut oak	Post oak
Virginia pine	Black oak	Sassafras
White oak	S. red oak	Red maple
N. red oak	Scarlet oak	Blackgum
Yellow-poplar	Elms	Dogwood
	Sweetgum	Sourwood
		Persimmon

Description of Landtype 3:
Broad Ridges—North Aspect

Geographic Setting—Deep, silty and cherty soils on gently sloping to rolling north-facing portions of broad ridgetops and adjoining convex upper slopes in Subregion 1. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 15 percent. Soils developed in 2 to 3.5 feet of loess over clayey residuum from limestone some of which is cherty. Chert constitutes as much as 35 percent of the soil mass and is concentrated in the lower solum. Chert fragments occur on the surface in places.

Dominant Soils—Mountview, Dickson, and Bewleyville.

Bedrock—Limestone and cherty limestone.

Depth to Bedrock—More than 6 feet. Dickson soils have a fragipan at depths of 24 to 36 inches.

Texture—Silt loam.

Soil Drainage—Well drained to moderately well drained.

Relative Soil Water Supply—Medium.

Soil Fertility—Moderately low.

Vegetation—White oak, southern red oak, black oak, northern red oak, hickories, blackgum, shortleaf pine, and loblolly pine; occasional scarlet oak, chestnut oak, post oak, yellow-poplar, red maple, black walnut, white ash, black cherry, and Virginia pine. Dogwood, sourwood, sassafras, persimmon, huckleberries, and winged elm are common in the understory.

ble 7.—*Forest management interpretations for Landtype 3: Broad Ridges—North Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	80	55	123	133
Shortleaf pine	65	(50)	113	119
Virginia pine	65		70	
Upland oaks	70		57	
Yellow-poplar	90		90	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Medium	Slight	Slight	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Virginia pine	Post oak
Loblolly pine	Hickories	Sassafras
Black walnut	Chestnut oak	Red maple
White oak	Black oak	Blackgum
N. red oak	S. red oak	Dogwood
Yellow-poplar	Scarlet oak	Sourwood
Black cherry		Persimmon
White ash		

Description of Landtype 4:
Broad Ridges—South Aspect

Geographic Setting—Deep, silty and cherty soils on gently sloping to rolling south-facing portions of broad ridgetops and adjoining convex upper slopes in Subregion 1. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 15 percent. South-facing ridges tend to be somewhat steeper and have shallower soils with a higher chert content than north-facing ridges. Soils developed in 2 to 3.5 feet of loess over clayey residuum from limestone, some of which is cherty. Chert constitutes as much as 35 percent of the soil mass and is concentrated in the lower solum. Chert fragments occur on the surface in places.

Dominant Soils—Mountview, Dickson, and Bewleyville.

Bedrock—Limestone and cherty limestone.

Depth to Bedrock—More than 6 feet. Dickson soils have a fragipan at depths of 24 to 36 inches.

Texture—Silt loam.

Soil Drainage—Well drained to moderately well drained.

Relative Soil Water Supply—Medium to low.

Soil Fertility—Moderately low.

Vegetation—Southern red oak, scarlet oak, post oak, white oak, chestnut oak, hickories, blackgum, shortleaf pine, loblolly pine, and Virginia pine; occasional black oak, red maple, yellow-poplar, and eastern redcedar. Sassafras, sourwood, dogwood, huckleberries, persimmon, and winged elm are common in the understory.

Table 8.—*Forest management interpretations for Landtype 4: Broad Ridges—South Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	75	50	114	117
Shortleaf pine	60	(45)	102	102
Virginia pine	60		46	
Upland oaks	65		51	
Yellow-poplar	80		71	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Slight	Slight	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	White oak	Post oak
Virginia pine	Chestnut oak	Winged elm
Yellow-poplar	Black oak	Sassafras
	S. red oak	Red maple
	Scarlet oak	Blackgum
		Dogwood
		Sourwood
		Persimmon

Description of Landtype 5:
Cherty North Slopes

Geographic Setting—Moderately deep to deep, silty and clayey soils that are mostly cherty on gently sloping to very steep north-facing linear or nearly linear midslopes in Subregion 1. This landtype lies between the narrow winding ridgetops, broad undulating uplands, and broad ridgetops and convex upper slopes (Landtypes 1, 2, 3, 12, 13, and 14) and the lower concave footslopes, terraces, and bottoms of streams and creeks (Landtypes 9 and 10) or footslopes, terraces, and floodplains of major river bottoms (Landtypes 42 and 47). Slope ranges from 6 to 60 percent. Chert fragments and limestone outcrops are common on the surface. As much as 85 percent of the soil mass may be coarse fragments.

Dominant Soils—Bodine and Fullerton. Talbott soils are also common in an irregular band east of the Tennessee River in Wayne and Perry Counties, Tennessee (Soil Association D12).

Bedrock—Limestone and cherty limestone.

Depth to Bedrock—More than 60 inches to cherty limestone under Bodine and Fullerton soils and 20 to 40 inches to limestone under Talbott soils.

Texture—Cherty silt loam, cherty loam, and silt loam. Eroded areas have finer texture.

Soil Drainage—Well drained to somewhat excessively drained.

Relative Soil Water Supply—High to medium. Irrigated by subsurface flow.

Soil Fertility—Moderate to moderately low.

Vegetation—White oak, black oak, southern red oak, yellow-poplar, northern red oak, hickories, blackgum, red maple; occasional scarlet oak, chestnut oak, post oak, elms, white ash, black walnut, black cherry, eastern redcedar, American beech, sugar maple, shortleaf pine, loblolly pine, and Virginia pine. Dogwood, sassafras, persimmon, eastern hophornbeam, American hornbeam, sourwood, eastern redbud, devil's club, euonymus, hydrangea, and huckleberries are common in the understory.

Table 9.—*Forest management interpretations for Landtype 5: Cherty North Slopes Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index: Natural stands[1]	Site index: Old-field plantations[2]	Average annual growth Cubic feet per acre: Natural stands[3]	Average annual growth Cubic feet per acre: Old-field plantations[4]
Loblolly pine	75	55	114	133
Shortleaf pine	65	45	113	102
Virginia pine	70		92	
E. redcedar	50		...	
Black oak S. red oak	70		52	
Yellow-poplar	90		90	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Medium	Slight to moderate	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	Post oak	American hornbeam
Virginia pine	Chestnut oak	E. hophornbeam
Black walnut	Black oak	American beech
White oak	S. red oak	Sassafras
N. red oak	Scarlet oak	E. redbud
Yellow-poplar	Elms	Maples
Black cherry		Blackgum
White ash		Dogwood
		Sourwood
		Persimmon

Description of Landtype 6:
Cherty South Slopes

Geographic Setting—Moderately deep to deep, silty and clayey soils that are mostly cherty on gently sloping to very steep south-facing linear or nearly linear midslopes in Subregion 1. This landtype lies between the narrow winding ridgetops, broad undulating uplands, and broad ridges and convex upper slopes (Landtypes 1, 2, 4, 12, 13, and 15) and the lower concave footslopes, terraces, and bottoms of streams and creeks (Landtypes 9 and 10) or footslopes, terraces, and floodplains of major river bottoms (Landtypes 42 and 47). Slope ranges from 6 to 60 percent. Chert fragments and limestone outcrops are common on the surface. As much as 85 percent of the soil mass may be coarse fragments. South-facing slopes tend to be steeper and have shallower soils with higher rock contents than north-facing slopes.

Dominant Soils—Bodine and Fullerton. Talbott soils are common in an irregular band east of the Tennessee River in Wayne and Perry Counties, Tennessee (Soil Association D12).

Bedrock—Limestone and cherty limestone.

Depth to Bedrock—More than 60 inches to cherty limestone under Bodine and Fullerton soils and 20 to 40 inches to limestone under Talbott soils.

Texture—Cherty silt loam, cherty loam, and silt loam. Eroded areas have finer texture.

Soil Drainage—Well drained to somewhat excessively drained.

Relative Soil Water Supply—Medium to low.

Soil Fertility—Moderately low.

Vegetation—White oak, scarlet oak, chestnut oak, post oak, hickories, black oak, southern red oak, eastern redcedar, loblolly pine, Virginia pine, and shortleaf pine; occasional red maple, elms, blackgum, and yellow-poplar. Sourwood, dogwood, huckleberries, euonymus, winged elm, sassafras, and wild plum are common in the understory.

able 10.—*Forest management interpretations for Landtype 6: Cherty South Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	65	55	95	133
Shortleaf pine	55	(45)	90	102
Virginia pine	60		53	
E. redcedar	40		...	
Chestnut oak Scarlet oak	55		38	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	White oak	Post oak
Virginia pine	Chestnut oak	Winged elm
	Black oak	Red maple
	S. red oak	Blackgum
	Scarlet oak	Dogwood
	Elms	Sourwood
	Yellow-poplar	

Description of Landtype 7: Shaly North Slopes

Geographic Setting—Moderately deep to deep, silty soils that are shaly or cherty and situated on long strongly sloping to very steep north-facing linear to concave slopes above streams (Landtypes 9 and 10) that have cut deeply into the Highland Rim plateau in Subregion 1. These shaly north slopes occur below ridges and convex upper slopes (Landtypes 1 and 3) and cherty sideslopes (Landtype 5). Landtype 7 differs from Landtype 16 in Subregion 2 (Highland Rim-Nashville Basin transition) in that the streams have not cut down into phosphatic limestone. Slope ranges from 15 to 50 percent. Outcrops of shale and limestone are common but not extensive. Fifty percent or more of the soil mass may be shale, chert, or limestone fragments.

Dominant Soils—Sulphura and an undefined soil that is 3 to 4 feet to interbedded chert and shale.

Bedrock—Shale and thin lenses of limestone.

Depth to Bedrock—1 to 4 feet.

Texture—Shaly silt loam. In places cherty material has drifted downslope.

Soil Drainage—Well drained to excessively drained.

Relative Soil Water Supply — High to medium. Irrigated by subsurface flow.

Soil Fertility—Moderate to moderately low.

Vegetation—White oak, black oak, southern red oak, yellow-poplar, blackgum, red maple, northern red oak, and hickories; occasional scarlet oak, chestnut oak, elms, white ash, black walnut, black cherry, American beech, sugar maple, black locust, eastern redcedar, loblolly pine, shortleaf pine, and Virginia pine. Dogwood, sassafras, eastern hophornbeam, winged elm, American hornbeam, sourwood, huckleberries, eastern redbud, euonymus, and huckleberries are common in the understory.

able 11.–*Forest management interpretations for Landtype 7: Shaly North Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index Natural stands[1]	Site index Old-field plantations[2]	Average annual growth Cubic feet per acre Natural stands[3]	Average annual growth Cubic feet per acre Old-field plantations[4]
Loblolly pine	65		95	
Shortleaf pine	55		90	
Virginia pine	55		41	
E. redcedar	35		...	
White oak	55		38	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Severe	Moderate	Severe	Moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	Chestnut oak	American hornbeam
Virginia pine	Black oak	E. hophornbeam
Black walnut	S. red oak	American beech
White oak	Scarlet oak	Winged elm
N. red oak	Elms	Sassafras
Yellow-poplar		E. redbud
Black cherry		Black locust
White ash		Maples
		Blackgum
		Dogwood
		Sourwood

Description of Landtype 8:
Shaly South Slopes

Geographic Setting–Moderately deep to deep, silty soils that are shaly or cherty and situated on long strongly sloping to very steep south-facing linear to concave slopes above streams (Landtypes 9 and 10) that have cut deeply into the Highland Rim plateau in Subregion 1. These shaly south slopes occur below the ridges and convex upper slopes (Landtypes 1 and 4) and cherty sideslopes (Landtype 6). Landtype 8 differs from Landtype 17 in Subregion 2 (Highland Rim-Nashville Basin transition) in that the streams have not cut down into phosphatic limestone. Slope ranges from 15 to 50 percent. Outcrops of shale and limestone are common but not extensive. Fifty percent or more of the soil mass may be shale, chert, or limestone fragments. South-facing slopes tend to be steeper and have shallower soils with higher rock content than north-facing slopes.

Dominant Soils–Sulphura and an undefined soil that is 3 to 4 feet to interbedded chert and shale.

Bedrock–Shale and thin lenses of limestone.

Depth to Bedrock–1 to 4 feet.

Texture–Shaly silt loam. In places cherty material has drifted downslope.

Soil Drainage–Well drained to excessively drained.

Relative Soil Water Supply–Low. Irrigated by subsurface flow but south slopes dry quickly.

Soil Fertility–Low.

Vegetation–White oak, scarlet oak, chestnut oak, hickories, southern red oak, black oak, eastern redcedar, loblolly pine, shortleaf pine, and Virginia pine; occasional elms, yellow-poplar, blackgum, American beech, white ash, sugar maple, black walnut, black cherry, and red maple. Dogwood, sassafras, sourwood, winged elm, huckleberries, eastern hophornbeam, American hornbeam, and euonymus are common in the understory.

able 12.—*Forest management interpretations for Landtype 8: Shaly South Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index Natural stands[1]	Site index Old-field plantations[2]	Average annual growth Cubic feet per acre Natural stands[3]	Average annual growth Cubic feet per acre Old-field plantations[4]
Loblolly pine	60		86	
Shortleaf pine	50		79	
Virginia pine	50		<41	
E. redcedar	30		...	
White oak	50		32	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Severe	Moderate to severe	Severe	Moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Black walnut	E. redcedar
Loblolly pine	Hickories	American hornbeam
Virginia pine	Chestnut oak	E. hophornbeam
White oak	Black oak	American beech
S. red oak	Scarlet oak	Winged elm
	Elms	Sassafras
	Yellow-poplar	Maples
	Black cherry	Blackgum
	White ash	Dogwood
		Sourwood

Description of Landtype 9: Footslopes, Terraces, Streambottoms, and Upland Depressions With Good Drainage

Geographic Setting—Deep and very deep, silty and loamy soils with good drainage on level to steep concave footslopes, terraces, and streambottoms, and in upland depressions in Subregion 1. Slope ranges from 0 to 45 percent. This landtype typically occurs below Landtypes 5 to 8 as long, narrow strips along intermittent drainages and as level bottomlands along permanent streams. It may also occur as small isolated depressions in Landtypes 3 and 4. When Landtypes 9 and 10 are adjacent, Landtype 9 occupies a higher position on the landscape.

Dominant Soils—Cherty Minvale, Humphreys, Ennis, Cannon, and Lobelville, and the noncherty Etowah, Emory, Choccolocco, Pruitton, and Staser.

Parent Material—Alluvium from cherty limestone, limestone, and loess.

Depth to Bedrock—5 to 15 feet.

Texture — Cherty silt loam, cherty loam, silt loam, loam, and rarely silty clay loam and fine sandy loam.

Soil Drainage—Well drained to moderately well drained.

Relative Soil Water Supply—High. Irrigated by subsurface drainage.

Soil Fertility—Moderately high.

Vegetation—White oak, yellow-poplar, southern red oak, northern red oak, blackgum, hickories, sweetgum, red maple, and American sycamore; occasional cottonwood, elms, American beech, hackberry, black oak, eastern redcedar, black walnut, black cherry, white ash, sugar maple, loblolly pine, shortleaf pine, and Virginia pine. Dogwood, cane, winged elm, persimmon, American hornbeam, eastern hophornbeam, eastern redbud, huckleberries, sassafras, sourwood, pawpaw, euonymus, hawthorns, and hydrangea are common in the understory.

able 13.—*Forest management interpretations for Landtype 9: Footslopes, Terraces, Streambottoms, and Upland Depressions with Good Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	90	55	144	133
Shortleaf pine	75	(50)	136	120
Virginia pine	70		92	
Upland oaks	80		62	
Yellow-poplar	100		107	
Sweetgum	90		81	
Cottonwood	95		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	Shortleaf pine	E. redcedar
Cottonwood	Virginia pine	American hornbeam
Black walnut	Hickories	E. hophornbeam
N. red oak	White oak	American beech
Yellow-poplar	Black oak	Winged elm
Sweetgum	S. red oak	Hackberry
American sycamore	Elms	Sassafras
Black cherry		E. redbud
White ash		Maples
		Blackgum
		Dogwood
		Sourwood
		Persimmon

Description of Landtype 10:
Terraces, Streambottoms, and Upland Depressions with Poor Drainage

Geographic Setting—Deep and very deep, silty and loamy soils with poor drainage on level to nearly level terraces and streambottoms, and in upland depressions in Subregion 1. Slope ranges from 0 to 2 percent. This landtype typically occurs below Landtypes 5 to 8 as long, narrow strips along intermittent drainages and as level bottomlands along permanent streams and creeks. It may also occur as small isolated depressions in Landtypes 3 and 4. When Landtypes 9 and 10 are adjacent, Landtype 10 occupies a lower position on the landscape.

Dominant Soils—Cherty Lee and noncherty Chenneby.

Parent Material—Alluvium from cherty limestone, limestone, and loess.

Depth to Bedrock—More than 5 feet.

Texture—Cherty silt loam, cherty loam, and silt loam.

Soil Drainage—Somewhat poorly drained to poorly drained.

Relative Soil Water Supply—Very high to high. Irrigated by subsurface flow. Seasonal water table.

Soil Fertility—Moderately high.

Vegetation—Sweetgum, elms, blackgum, red maple, American sycamore, and white oak; occasional willow oak, water oak, silver maple, cottonwood, green ash, yellow-poplar, loblolly pine, black willow, American beech, and hickories. Alder, witch-hazel, cane, hydrangea, dogwood, and huckleberries are common in the understory.

ble 14.—*Forest management interpretations for Landtype 10: Terraces, Streambottoms, and Upland Depressions with Poor Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	95		156	
Bottomland oaks	95		...	
Yellow-poplar	100		107	
Sweetgum	95		93	
White oak	90		>62	
American sycamore	100		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Moderate to severe	Moderate to severe	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	Hickories	Black willow
Cottonwood	White oak	American beech
Willow oak	Elms	Maples
Water oak	Yellow-poplar	Blackgum
Sweetgum	American sycamore	Dogwood
Green ash		

Description of Landtype 11: Limestone Rockland and Shallow Soils

Geographic Setting–Small to extensive areas of limestone outcrops interspersed with patches of shallow to moderately deep, clayey soils on gently sloping to moderately steep ridgetops and slopes, along incised streams, and in sinkholes in Subregions 1, 2, and 3. This intricate pattern of soils and rockland occurs in association with many landtypes. Eastern redcedar often dominates this landtype. Slope ranges from 1 to 40 percent. Soil mass may contain up to 35 percent limestone slabs. More than 50 percent of the surface may be exposed limestone rock. Where the exposed rock is extensive, it is often terraced, but the slope of each terrace is nearly horizontal.

Dominant Soils–Barfield, Gladeville, Fairmount, and Corydon, and Limestone Rockland. Barfield and Gladeville soils have a thermic temperature regime and are common to Alabama and Tennessee; Fairmount and Corydon soils have a mesic temperature regime and are common to Kentucky. Pockets of moderately deep Talbott (thermic), Fredonia (mesic), and Caneyville (mesic) soils may occur in this landtype.

Bedrock–Limestone.

Depth to Bedrock–Mostly less than 20 inches but ranges up to 40 inches where Talbott, Fredonia, and Caneyville soils occur.

Texture–Silt loam, silty clay loam, and silty clay.

Soil Drainage–Well drained to excessively drained.

Relative Soil Water Supply–Low. Seepage is common in wet weather but the soil dries quickly.

Soil Fertility–Moderate.

Vegetation–Eastern redcedar, hickories, hackberry, rock elm, chinkapin oak, and post oak; occasional bur oak, honeylocust, Virginia pine, blackjack oak, blue ash, and white ash. Forbs, grasses, sumac, eastern redbud, winged elm, osage-orange, buckthorn, hawthorns, and prickly pear are common in the understory.

Table 15.—*Forest management interpretations for Landtype 11: Limestone Rockland and Shallow Soils. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
E. redcedar	40		...	
Virginia pine	55		41	
Upland oaks	(55)		43	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Severe	Moderate to severe	Moderate to severe	Moderate to severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Virginia pine	Hickories	Blackjack oak
E. redcedar	Bur oak	Winged elm
	Post oak	Hackberry
	Chinkapin oak	Osage-orange
	Rock elm	E. redbud
	White ash	Honeylocust
	Blue ash	

Description of Landtype 12:
Broad Silty Uplands

Geographic Setting–Deep, silty soils on gently sloping to strongly sloping broad uplands in Subregions 1, 2, and 3. Slope ranges from 1 to 15 percent but is commonly 6 percent or less, and aspect is not a dominant site factor. This landtype occurs mostly in Landtype Association C where it may exceed 0.25 mile in width. Extensive areas with greater slope should be classified as Landtypes 3 or 4. In Landtype Association E, this landtype generally is 250 to 500 feet wide and occupies the scattered higher portions of the knobby landscape in association with the predominant steep, narrow ridges (Landtype 1). In Landtype Association G, this landtype is of limited extent and occupies the higher and broader portions of the karst plain in association with Landtypes 23, 24, and 25.

Dominant Soils–Mountview and Dickson.

Bedrock–Cherty limestone.

Depth to Bedrock–More than 6 feet. Dickson soils have fragipans at depths ranging from 24 to 36 inches.

Texture–Silt loam.

Soil Drainage–Well drained and moderately well drained.

Relative Soil Water Supply–Low to medium.

Soil Fertility–Moderately low.

Vegetation–Southern red oak, post oak, scarlet oak, blackjack oak, hickories, white oak, and blackgum; occasional chestnut oak, black oak, eastern redcedar, black cherry, elms, shortleaf pine, Virginia pine, loblolly pine, yellow-poplar, sweetgum, and red maple. Dogwood, huckleberries, sourwood, sassafras, and winged elm are common in the understory.

able 16.—*Forest management interpretations for Landtype 12: Broad Silty Uplands. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	80	(50)	123	117
Shortleaf pine	65	(40)	113	84
Virginia pine	60		53	
Upland oaks	70		52	
Yellow-poplar	(75)		90	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight	Slight	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	White oak	Blackjack oak
Virginia pine	Post oak	Elms
Black oak	Chestnut oak	Sassafras
S. red oak	Yellow-poplar	Red maple
Scarlet oak	Sweetgum	Blackgum
	Black cherry	Dogwood
		Sourwood

Description of Landtype 13:
Broad Undulating Uplands

Geographic Setting—Deep, silty and clayey soils on nearly level to gently sloping uplands in Subregion 1. Slope generally does not exceed 6 percent, and aspect is not a dominant site factor. This landtype may be 0.5 mile or more wide. Typically it occupies the highest part of the landscape and grades into Landtypes 5 and 6. Sinkholes and depressions are common.

Dominant Soils—Bewleyville, Curtistown, Decatur, Dewey, and Waynesboro.

Bedrock—Limestone.

Depth to Bedrock—More than 5 feet.

Texture—Silt loam, loam, silty clay loam; some chert in the lower horizons.

Soil Drainage—Well drained.

Relative Soil Water Supply—High to medium.

Soil Fertility—Moderately low.

Vegetation—Southern red oak, scarlet oak, white oak, black oak, yellow-poplar, hickories, elms, red maple, and eastern redcedar; occasional American beech, black walnut, loblolly pine, shortleaf pine, Virginia pine, white ash, black cherry, and hackberry. Dogwood, persimmon, sassafras, red mulberry, and sourwood are common in the understory.

able 17.—*Forest management interpretations for Landtype 13: Broad Undulating Uplands. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	80	(50)	123	117
Shortleaf pine	75		136	
Virginia pine	75		120	
E. redcedar	45		...	
S. red oak	70		52–62	
White oak	75			
Yellow-poplar	90		90	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight to moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	Black oak	American beech
Virginia pine	S. red oak	Hackberry
Black walnut	Scarlet oak	Red mulberry
White oak	Elms	Sassafras
Yellow-poplar		Red maple
Black cherry		Dogwood
White ash		Sourwood
		Persimmon

Description of Landtype 14:
Broad Ridges–North Aspect

Geographic Setting–Deep, mostly clayey soils on gently sloping to hilly north-facing portions of broad ridgetops and adjoining convex upper slopes in Subregion 1. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 25 percent. In Fullerton soils chert constitutes as much as 35 percent of the soil mass. When the land is cleared, erosion is a problem on the steeper parts.

Dominant Soils–Decatur, Dewey, and Fullerton.

Bedrock–Limestone.

Depth to Bedrock–More than 5 feet.

Texture–Silt loam, loam, cherty silt loam, and cherty loam; if eroded, silty clay loam, silty clay, or cherty silty clay loam.

Soil Drainage–Well drained.

Relative Soil Water Supply–Medium.

Soil Fertility–Moderate to moderately high.

Vegetation–Southern red oak, scarlet oak, white oak, black oak, red maple, hickories, yellow-poplar, and eastern redcedar; occasional American beech, elms, white ash, black walnut, black cherry, loblolly pine, shortleaf pine, and Virginia pine. Dogwood, persimmon, sassafras, sourwood, and red mulberry are common in the understory.

ble 18.—*Forest management interpretations for Landtype 14: Broad Ridges—North Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index Natural stands[1]	Site index Old-field plantations[2]	Average annual growth Cubic feet per acre Natural stands[3]	Average annual growth Cubic feet per acre Old-field plantations[4]
Loblolly pine	75	(55)	114	133
Shortleaf pine	70		125	
Virginia pine	70		92	
E. redcedar	50		...	
White oak	70		52	
S. red oak	70			
Yellow-poplar	90		90	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight to moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	Black oak	American beech
Virginia pine	Scarlet oak	Red mulberry
Black walnut	Elms	Sassafras
White oak		Red maple
S. red oak		Dogwood
Yellow-poplar		Sourwood
Black cherry		Persimmon
White ash		

Description of Landtype 15:
Broad Ridges–South Aspect

Geographic Setting–Deep, mostly clayey soils on gently sloping to hilly south-facing portions of broad ridgetops and adjoining convex upper slopes in Subregion 1. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 25 percent. South-facing ridges tend to be somewhat steeper and have shallower soils than north-facing ridges. In Fullerton soils chert constitutes as much as 35 percent of the soil mass. When the land is cleared, erosion is a problem on the steeper parts.

Dominant Soils–Decatur, Dewey, and Fullerton.

Bedrock–Limestone.

Depth to Bedrock–More than 5 feet.

Texture–Silt loam, loam, cherty silty loam, and cherty loam; if eroded, silty clay loam, silty clay, or cherty silty clay loam.

Soil Drainage–Well drained.

Relative Soil Water Supply–Medium.

Soil Fertility–Moderate to moderately high.

Vegetation–Southern red oak, scarlet oak, hickories, white oak, black oak, and eastern redcedar; occasional yellow-poplar, chestnut oak, post oak, red maple, elms, loblolly pine, shortleaf pine, and Virginia pine. Dogwood, persimmon, sassafras, sourwood, and huckleberries are common in the understory.

ble 19.—*Forest management interpretations for Landtype 15: Broad Ridges—South Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	70	(50)	104	117
Shortleaf pine	65		113	
Virginia pine	65		70	
E. redcedar	40		...	
White oak	65		48	
S. red oak	65			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	Post oak	Sassafras
Virginia pine	Chestnut oak	Red maple
White oak	Black oak	Dogwood
S. red oak	Scarlet oak	Sourwood
	Elms	Persimmon
	Yellow-poplar	

Description of Landtype 16:
North Slopes

Geographic Setting–Moderately deep to deep, silty and clayey, soils that are mostly shaly or cherty and situated on north-facing linear to concave midslopes and lower slopes in Subregion 2. This landtype lies between the high broad uplands or narrow winding ridges and knoblike hills and adjoining convex upper slopes (Landtypes 1 and 12) and lower slopes, terraces and streambottoms (Landtypes 18 and 19). Slope ranges from 2 to 50 percent but is mainly 20 to 40 percent. Sulphura soils contain 10 to 25 percent shale and chert fragments in the topsoil and 35 to 55 percent in the subsoil. Dellrose soils contain 10 to 35 percent chert fragments.

Dominant Soils–Sulphura, Dellrose, and Mimosa. Sulphura soils formed in a thin mantle of cherty material of high silt content over residuum from shale. Dellrose soils formed in cherty medium-textured creep more than 5 feet thick. Mimosa soils formed mostly in clayey residuum from limestone that was moderate to high in phosphates. Sulphura soils lie as narrow strips below Bodine and Fullerton soils and above Dellrose soils, which lie above Mimosa soils.

Bedrock–Shale and phosphatic limestone.

Depth to Bedrock–20 to 40 inches to shale; 60 to 80 or more inches to phosphatic limestone.

Texture–Cherty silt loam, cherty loam, or silt loam.

Soil Drainage–Somewhat excessively drained and well drained.

Relative Soil Water Supply–Medium to high. Irrigated by subsurface flow. Seeps occur in places.

Soil Fertility–Moderate to moderately high.

Vegetation–White oak, black oak, northern red oak, yellow-poplar, hickories, blackgum, elms, red maple, and American beech; occasional chestnut oak, scarlet oak, southern red oak, black walnut, white ash, black cherry, cucumbertree, hackberry, black locust, sassafras, eastern redcedar, and loblolly pine. Dogwood, eastern redbud, American hornbeam, eastern hophornbeam, devil's club, pawpaw, huckleberries, and euonymus are common in the understory.

able 20.—*Forest management interpretations for Landtype 16: North Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	75		114	
N. red oak	75		52–57	
White oak	(70)			
Yellow-poplar	100		107	
Hickories	(75)		...	
Black walnut	(75)		...	
White ash	(75)		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Slight to moderate	Slight to moderate	Moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	Hickories	E. redcedar
Black walnut	Chestnut oak	American hornbeam
White oak	Black oak	E. hophornbeam
N. red oak	S. red oak	American beech
Yellow-poplar	Scarlet oak	Hackberry
Black cherry	Elms	Sassafras
White ash	Cucumbertree	E. redbud
		Black locust
		Maples
		Blackgum
		Dogwood
		Sourwood

Description of Landtype 17:
South Slopes

Geographic Setting–Moderately deep to deep, silty and clayey soils that are mostly shaly or cherty and situated on south-facing linear to concave midslopes and lower slopes in Subregion 2. This landtype lies between the high broad uplands or narrow winding ridges and knoblike hills and adjoining convex upper slopes (Landtypes 1 and 12) and lower slopes, terraces, and streambottoms (Landtypes 18 and 19). Slope ranges from 2 to 50 percent but is mainly 20 to 40 percent. South-facing slopes tend to be steeper and have shallower soils with higher rock contents than north-facing slopes. Sulphura soils contain 10 to 25 percent shale and chert fragments in the topsoil and 35 to 55 percent in the subsoil. Dellrose soils contain 10 to 35 percent chert fragments.

Dominant Soils–Sulphura, Dellrose, and Mimosa. Sulphura soils formed in a thin mantle of cherty material of high silt content over residuum from shale. Dellrose soils formed in cherty medium-textured creep more than 5 feet thick. Mimosa soils formed mostly in residuum from limestone that was moderate to high in phosphates. Sulphura soils lie as narrow strips below Bodine and Fullerton soils and above Dellrose soils, which lie above Mimosa soils.

Bedrock–Shale and phosphatic limestone.

Depth to Bedrock–20 to 40 inches to shale; 60 to 80 or more inches to phosphatic limestone.

Texture–Cherty silt loam, cherty loam, or silt loam.

Soil Drainage–Somewhat excessively drained and well drained.

Relative Soil Water Supply–Medium. Irrigated by subsurface flow.

Soil Fertility–Moderate.

Vegetation–White oak, scarlet oak, southern red oak, black oak, chestnut oak, and hickories; occasional red maple, blackgum, elms, black locust, chinkapin oak, yellow-poplar, American beech, black walnut, black cherry, sugar maple, white ash, eastern redcedar, and loblolly pine. Dogwood, sassafras, sourwood, eastern redbud, and hawthorns are common in the understory.

able 21.—*Forest management interpretations for Landtype 17: South Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	65		95	
Upland oaks	60		43	
E. redcedar	45		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Slight to moderate	Slight to moderate	Moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	E. redcedar	American beech
White oak	Black walnut	Sassafras
Black oak	Hickories	E. redbud
S. red oak	Chestnut oak	Black locust
	Chinkapin oak	Maples
	Scarlet oak	Blackgum
	Elms	Dogwood
	Yellow-poplar	Sourwood
	Black cherry	
	White ash	

Description of Landtype 18: Footslopes, Terraces, and Streambottoms with Good Drainage

Geographic Setting—Deep, mostly silty soils with good drainage on level to strongly sloping footslopes, terraces, and streambottoms in Subregion 2. Slope ranges from 0 to 12 percent. This landtype typically occurs below Landtypes 16, 17, 21 and 22 as long, narrow strips along intermittent drainages and as level bottomlands along permanent streams. When Landtypes 18 and 19 are adjacent, Landtype 18 occupies a higher position on the landscape.

Dominant Soils—Armour, Britton, Arrington, Egam, and Lynnville.

Parent Material—Mostly alluvium washed from soils developed in residuum from phosphatic limestone. Armour soils developed in 2 to 4 feet of loess over alluvium.

Depth to Bedrock—4 to 15 feet to phosphatic limestone.

Texture—Silt loam and silty clay loam.

Soil Drainage—Well drained to moderately well drained.

Relative Soil Water Supply—High. Footslopes irrigated by subsurface flow. Terraces and bottoms subject to occasional flooding.

Soil Fertility—High to moderately high.

Vegetation—White oak, northern red oak, red maple, blackgum, southern red oak, hickories, sweetgum, and American sycamore; occasional American beech, elms, hackberry, yellow-poplar, sugar maple, cottonwood, boxelder, river birch, black cherry, black walnut, white ash, eastern redcedar, shortleaf pine, and loblolly pine. Dogwood, cane, osage-orange, and euonymus are common in the understory.

able 22.—*Forest management interpretations for Landtype 18: Footslopes, Terraces, and Streambottoms with Good Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index Natural stands[1]	Site index Old-field plantations[2]	Average annual growth Cubic feet per acre Natural stands[3]	Average annual growth Cubic feet per acre Old-field plantations[4]
Loblolly pine	90		144	
Shortleaf pine	80		148	
White oak	80		62	
S. red oak	80			
Yellow-poplar	100		107	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate to severe	Slight	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	Elms	River birch
Cottonwood	American sycamore	American beech
Black walnut		Hackberry
White oak		Osage-orange
N. red oak		Maples
S. red oak		Blackgum
Yellow-poplar		Dogwood
Sweetgum		
Black cherry		
White ash		

Description of Landtype 19:
Terraces and Streambottoms with Poor Drainage

Geographic Setting—Deep, mostly clayey soils with poor drainage on level to gently sloping terraces and streambottoms in Subregion 2. Slope ranges from 0 to 5 percent. This landtype typically occurs below landtypes 16, 17, 21, and 22 as long, narrow strips along intermittent drainages and on level bottomlands along permanent streams. When Landtypes 18 and 19 are adjacent, Landtype 19 occupies a lower position on the landscape.

Dominant Soils—Godwin, Lanton, and Mhoon.

Parent Material—Alluvium washed from soils developed in residuum from phosphatic limestone and a variable amount of loess.

Depth to Bedrock—More than 5 feet to phosphatic limestone.

Texture—Silt loam and silty clay loam.

Soil Drainage—Somewhat poorly drained to poorly drained.

Relative Soil Water Supply—High to very high. Soils have a seasonally fluctuating water table and are subject to occasional flooding.

Soil Fertility—High.

Vegetation—Willow oak, water oak, sweetgum, red maple, blackgum, green ash, and American sycamore; occasional boxelder, elms, white ash, yellow-poplar, cottonwood, hickories, and loblolly pine. Dogwood and cane are common in the understory.

ble 23.—*Forest management interpretations for Landtype 19: Terraces and Streambottoms with Poor Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	90		144	
Water oak	90		...	
Sweetgum	95		93	
Cottonwood	105		...	
Green ash	90		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Moderate to severe	Moderate to severe	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	Hickories	Red maple
Cottonwood	Elms	Boxelder
Willow oak	Yellow-poplar	Blackgum
Water oak	American sycamore	Dogwood
Sweetgum	White ash	
Green ash		

Description of Landtype 20:
Low Broad Ridges

Geographic Setting—Deep, silty and clayey soils on nearly level to sloping broad, smooth tops of low-lying hills below the surrounding higher ridges and slopes (Landtypes 1, 5–8, and 12) in Subregion 2. Slope ranges from 0 to 10 percent but is usually 6 percent or less, and aspect is not a dominant site factor. Soils developed in 2 feet or less of loess over old alluvium or in old valley fill and residuum from phosphatic limestone.

Dominant Soils—Maury and Harpeth. Soils classified as Maury soils in the Nashville Basin are slightly warmer than the range defined for the series. But, because they are so similar in morphology, composition, and behavior to soils of the Maury series they are considered taxadjuncts to that series.

Bedrock—Phosphatic limestone.

Depth to Bedrock—5 to 15 feet.

Texture—Silt loam and silty clay loam. Some chert fragments occur in the lower horizons of Maury soils.

Soil Drainage—Well drained.

Relative Soil Water Supply—Medium to high.

Soil Fertility—Moderately high to high.

Vegetation—White oak, northern red oak, black oak, hickories, sugar maple, scarlet oak, southern red oak, elms, white ash, and eastern redcedar; occasional hackberry, American beech, chinkapin oak, honeylocust, Kentucky coffeetree, yellow-poplar, black cherry, black walnut, shortleaf pine, and loblolly pine. Winged elm, persimmon, eastern redbud, and sassafras are common in the understory.

able 24.—*Forest management interpretations for Landtype 20: Low Broad Ridges. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	90		144	
Shortleaf pine	80		148	
E. redcedar	50		. . .	
N. red oak	80		62	
Yellow-poplar	90		90	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Slight	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	Chinkapin oak	American beech
Black walnut	Black oak	Winged elm
White oak	S. red oak	Hackberry
N. red oak	Scarlet oak	Sassafras
Yellow-poplar	Elms	E. redbud
Black cherry	Sugar maple	Kentucky coffeetree
White ash		Honeylocust
		Persimmon

Description of Landtype 21:
North Slopes and Narrow Ridges

Geographic Setting–Deep, clayey soils on north-facing linear and concave midslopes and lower slopes in Subregion 2. Slope ranges from 2 to 35 percent. This landtype usually occurs below landtype 20. When Landtype 21 occurs in association with low narrow ridges, all land up to the ridge crest is included. Landtypes 18 and 19 occur below this landtype. Soils developed in old valley fill and clayey residuum from phosphatic limestone. The top 2 feet of Braxton soils may contain as much as 30 percent chert fragments, and the surface layer of Mimosa soils may contain as much as 15 percent chert fragments.

Dominant Soils–Braxton and Mimosa. Limestone outcrops are associated with Mimosa soils.

Bedrock–Phosphatic limestone.

Depth to Bedrock–40 to more than 80 inches.

Texture–silt loam, silty clay loam, and cherty silt loam.

Soil Drainage–Well drained.

Relative Soil Water Supply–Medium.

Soil Fertility–Moderate to moderately high.

Vegetation–White oak, northern red oak, black oak, hickories, sugar maple, scarlet oak, southern red oak, elms, white ash, and eastern redcedar; occasional hackberry, American beech, chinkapin oak, honeylocust, Kentucky coffeetree, yellow-poplar, black cherry, black walnut, and loblolly pine. Winged elm, persimmon, eastern redbud, and sassafras are common in the understory.

ble 25.—*Forest management interpretations for Landtype 21: North Slopes and Narrow Ridges. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	80		123	
E. redcedar	50		...	
Upland oaks	70		52	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight to moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	Hickories	E. redcedar
Black walnut	Chinkapin oak	American beech
White oak	Black oak	Winged elm
N. red oak	S. red oak	Hackberry
Yellow-poplar	Scarlet oak	Sassafras
Black cherry	Elms	E. redbud
White ash	Sugar maple	Kentucky coffeetree
		Honeylocust
		Persimmon

Description of Landtype 22:
South Slopes and Narrow Ridges

Geographic Setting—Deep, clayey soils on south-facing linear and concave midslopes and lower slopes in Subregion 2. Slope ranges from 2 to 35 percent. This landtype usually occurs below Landtype 20. When Landtype 22 occurs in association with low, narrow ridges, all land up to the ridge crest is included. Landtypes 18 and 19 occur below this landtype. South-facing slopes tend to be steeper and have shallower soils with higher rock contents than north-facing slopes. Soils developed in old valley fill and clayey residuum from phosphatic limestone. As much as 30 percent of the top 2 feet of Braxton soils, and as much as 15 percent of the surface layer of Mimosa soils may be chert fragments.

Dominant Soils—Braxton and Mimosa. Limestone outcrops are associated with Mimosa soils.

Bedrock—Phosphatic limestone.

Depth to Bedrock—40 to more than 80 inches.

Texture—Silt loam, silty clay loam, and cherty silt loam.

Soil drainage—Well drained.

Relative Soil Water Supply—Medium to low.

Soil Fertility—Moderate to moderately high.

Vegetation—White oak, post oak, hickories, chinkapin oak, scarlet oak, and eastern redcedar; occasional honeylocust, chestnut oak, sugar maple, hackberry, American beech, Kentucky coffeetree, and loblolly pine. Winged elm, persimmon, eastern redbud, and sassafras are common in the understory.

ble 26.—*Forest management interpretations for Landtype 22: South Slopes and Narrow Ridges. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	70		104	
E. redcedar	45		...	
Upland oaks	60		43	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	E. redcedar	American beech
White oak	Hickories	Winged elm
Chestnut oak	Post oak	Sassafras
Scarlet oak	Chinkapin oak	E. redbud
		Kentucky coffeetree
		Honeylocust
		Sugar maple
		Persimmon

Description of Landtype 23:
Broad Undulating Uplands

Geographic Setting—Deep, mostly silty soils on nearly level to sloping broad uplands pitted with sinkholes and depressions in Subregion 3. Slope ranges from 1 to 10 percent but is commonly 6 percent or less, and aspect is not a dominant site factor. Soils developed in 1.5 to 4 feet of loess over residuum from limestone or in old alluvium. Volume of chert is negligible in the upper solum and ranges up to 15 percent in the lower solum below the discontinuity.

Dominant Soils—Pembroke, Crider, Nicholson, and Cumberland.

Bedrock—Limestone.

Depth to Bedrock—4 to 13 feet. Nicholson soils have fragipans at depths ranging from 16 to 30 inches.

Texture—Silt loam. Silty clay loam and clay loam in severely eroded areas.

Soil Drainage—Well drained to moderately well drained.

Relative Soil Water Supply—Medium to high.

Soil Fertility—Moderately high to high.

Vegetation—Black oak, white oak, southern red oak, scarlet oak, hickories, red maple, northern red oak, and elms; occasional yellow-poplar, American beech, bur oak, hackberry, black walnut, black cherry, white ash, sugar maple, eastern redcedar, shortleaf pine, Virginia pine, and loblolly pine. Eastern hophornbeam, persimmon, dogwood, and sassafras are common in the understory.

le 27.—*Forest management interpretations for Landtype 23: Broad Undulating Uplands. Footnotes*
tnotes appear on page 118.

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	80		123	
Shortleaf pine	80		148	
Virginia pine	80		158	
N. red oak	85		52->62	
White oak	70			
Yellow-poplar	95		98	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
hortleaf pine	Hickories	E. redcedar
oblolly pine	Bur oak	E. hophornbeam
irginia pine	Scarlet oak	American beech
lack walnut	Elms	Hackberry
hite oak	Sugar maple	Sassafras
. red oak		Red maple
lack oak		Dogwood
. red oak		Persimmon
ellow-poplar		
lack cherry		
hite ash		

Description of Landtype 24:
Broad Ridges—North Aspect

Geographic Setting—Deep, silty and clayey soils on sloping to moderately steep north-facing portions of broad ridgetops and adjoining convex upper slopes in Subregion 3. Sinkholes and depressions are common. Landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 20 percent. Soils developed in residuum from cherty limestone, old alluvium, or in 1.5 to 4 feet of loess over residuum from limestone. Volume of chert is 15 percent or less and concentrated in the lower solum, except Baxter soils, which may contain as much as 35 percent.

Dominant Soils—Pembroke, Baxter, Crider, Bewleyville, and Cumberland.

Bedrock—Limestone and cherty limestone.

Depth to Bedrock—5 to 10 feet.

Texture—Silt loam and cherty silt loam; if eroded, silty clay loam or cherty silty clay loam.

Soil Drainage—Well drained.

Relative Soil Water Supply—Medium.

Soil Fertility—Moderately high.

Vegetation—White oak, black oak, northern red oak, hickories, yellow-poplar, red maple, and elms; occasional southern red oak, scarlet oak, bur oak, American beech, black walnut, sugar maple, white ash, black cherry, eastern redcedar, shortleaf pine, Virginia pine, and loblolly pine. Sassafras, dogwood, persimmon, and eastern hophornbeam are common in the understory.

ble 28.—*Forest management interpretations for Landtype 24: Broad Ridges—North Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	80	(55)	123	133
Shortleaf pine	70		125	
Virginia pine	75		120	
E. redcedar	40		. . .	
N. red oak	90		52–>62	
White oak	70			
Yellow-poplar	95		98	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
hortleaf pine	Hickories	E. redcedar
oblolly pine	Bur oak	E. hophornbeam
irginia pine	Black oak	American beech
lack walnut	S. red oak	Sassafras
Vhite oak	Scarlet oak	Red maple
. red oak	Elms	Dogwood
ellow-poplar	Sugar maple	Persimmon
lack cherry		
Vhite ash		

Description of Landtype 25:
Broad Ridges—South Aspect

Geographic Setting—Deep, silty and clayey soils on sloping to moderately steep south-facing portions of broad ridgetops and adjoining convex upper slopes in Subregion 3. Sinkholes and depressions are common. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 20 percent. South-facing portions of ridges tend to be somewhat steeper and have shallower soils with a higher chert content than north-facing portions. Soils developed in residuum from cherty limestone, old alluvium, or in 1.5 to 4 feet of loess over residuum from limestone. Volume of chert is 15 percent or less and concentrated in the lower solum, except Baxter soils, which may contain as much as 35 percent.

Dominant Soils—Pembroke, Baxter, Crider, Bewleyville, and Cumberland.

Bedrock—Limestone and cherty limestone

Depth to Bedrock—5 to 10 feet.

Texture—Silt loam and cherty silt loam; if eroded, silty clay loam or cherty silty clay loam.

Soil Drainage—Well drained.

Relative Soil Water Supply—Medium to low.

Soil Fertility—Moderate to moderately high.

Vegetation—Black oak, white oak, scarlet oak, southern red oak, hickories, and eastern redcedar; occasional chestnut oak, bur oak, yellow-poplar, red maple, hackberry, elms, white ash, sugar maple, black walnut, black cherry, shortleaf pine, Virginia pine, and loblolly pine. Eastern hophornbeam, persimmon, dogwood, and sassafras are common in the understory.

ble 29.—*Forest management interpretations for Landtype 25: Broad Ridges—South Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	70	(50)	104	117
Shortleaf pine	(60)		102	
Virginia pine	65		70	
E. redcedar	35		...	
N. red oak	75		43–57	
White oak	60			
Yellow-poplar	(80)		71	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight to moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	Bur oak	E. hophornbeam
Virginia pine	Chestnut oak	Hackberry
Black walnut	Scarlet oak	Sassafras
White oak	Elms	Maples
Black oak		Dogwood
S. red oak		Persimmon
Yellow-poplar		
Black cherry		
White ash		

Description of Landtype 26:
Narrow Limestone Ridges and Knoblike Hills

Geographic Setting—Shallow to moderately deep, clayey soils on gently sloping to steep crests of knoblike hills, long narrow ridgetops, and adjoining convex to linear short slopes in Subregion 3. Short slopes extending down to stream terraces (Landtypes 31 and 32) are included. Slope ranges from 6 to 50 percent. This landtype is common to soil association D3 on the general soil map of Kentucky. Limestone outcrops may be extensive enough to recognize Landtype 11 (Limestone Rockland and Shallow Soils).

Dominant Soils—Hagerstown, Fredonia, and Caneyville.

Bedrock—Limestone.

Depth to Bedrock—20 inches to 5 feet.

Texture—Silt loam. Silty clay loam and silty clay in severely eroded areas.

Soil Draingage—Well drained.

Relative Soil Water Supply—Medium to low.

Soil Fertility—Moderate.

Vegetation—Southern red oak, post oak, hickories, hackberry, and eastern redcedar; occasional honeylocust, chinkapin oak, scarlet oak, sugar maple, black oak, white oak, and northern red oak. Eastern redbud, winged elm, sumac, and sassafras are common in the understory.

ble 30.—*Forest management interpretations for Landtype 26: Narrow Limestone Ridges and Knoblike Hills. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
E. redcedar	45		...	
Black oak	80		52–62	
N. red oak	70			
Scarlet oak	70			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Moderate	Moderate to severe	Moderate to severe	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
White oak	E. redcedar	Winged elm
N. red oak	Hickories	Sassafras
Black oak	Post oak	E. redbud
S. red oak	Chinkapin oak	Honeylocust
	Scarlet oak	
	Hackberry	
	Sugar maple	

Description of Landtype 27:
Upland Flats, Depressions, and Sinkholes with Good Drainage

Geographic Setting–Deep, silty soils with good drainage on level to gently sloping upland flats and depressions, and in sinkholes in Subregions 1 and 3. Landtype 28 occurs in association with broad silty uplands, broad undulating uplands, and broad ridges (Landtypes 12, 13, 23, 24, and 25). Slope is less than 6 percent. Flats and depressions may approach 20 acres in size; level bottoms of sinkholes are usually smaller.

Dominant Soils–Sango, Epley, Lindside, and Nolin. Thermic Sango soils are associated with Landtype 12 and 13 in Subregion 1. The other three soils are mesic and associated with Landtypes 23, 24, and 25 in Subregion 3.

Parent Material–Alluvium from limestone and loess, and loess over residuum from cherty limestone.

Depth to Bedrock–More than 4 feet. Sango soils have a fragipan at depths to 25 to 34 inches.

Texture–Silt loam; occasional silty clay loam and loam.

Soil Drainage–Moderately well drained to well drained.

Relative Soil Water Supply–High.

Soil Fertility–Moderate to moderately high.

Vegetation–White oak, southern red oak, black oak, hickories, red maple, northern red oak, scarlet oak, sweetgum, yellow-poplar, and elms; occasional black cherry, black walnut, white ash, sugar maple, American sycamore, American beech, bur oak, and eastern redcedar. Dogwood, sourwood, huckleberries, sassafras, and winged elm are common in the understory.

ble 31.—*Forest management interpretations for Landtype 27: Upland Flats, Depressions, and Sinkholes with Good Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
N. red oak	85			
White oak	85		52–>62	
Scarlet oak	70			
Yellow-poplar	90		90	
Sweetgum	85		70	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Black walnut	Hickories	E. redcedar
N. red oak	Bur oak	American beech
S. red oak	Black oak	Winged elm
White oak	Scarlet oak	Sassafras
Yellow-poplar	Elms	Maples
Sweetgum	American sycamore	Dogwood
Black cherry		Sourwood
White ash		

Description of Landtype 28:
Upland Flats, Depressions, and Sinkholes with Poor Drainage

Geographic Setting–Deep, silty soils with poor drainage on nearly level upland flats and depressions, and in sinkholes in Subregions 1 and 3. Landtype 28 occurs within broad silty uplands, broad undulating uplands, and broad ridges (Landtypes 12, 13, 23, 24, and 25). Slope is less than 3 percent. Flats and depressions may approach 20 acres in size; level bottoms of sinkholes are usually smaller.

Dominant Soils–Taft, Guthrie, Robertsville, Lawrence, and Newark. Thermic Taft and Guthrie soils are found in association with Landtypes 12 and 13 in Subregion 1, while mesic Robertsville, Lawrence, and Newark soils are associated with Landtypes 23, 24, and 25 in Subregion 3.

Parent Material–Alluvium from limestone and loess, and loess over residuum from cherty limestone.

Depth to Bedrock–More than 5 feet. All soils but Newark have fragipans at depths of 20 to 40 inches.

Texture–Silt loam; occasional silty clay loam and loam.

Soil Drainage–Somewhat poorly drained to poorly drained.

Relative Soil Water Supply–High to very high. Often flooded for short periods during winter and spring.

Soil Fertility–Moderate to moderately high.

Vegetation–Willow oak, blackgum, sweetgum, red maple, yellow-poplar, and elms; occasional hickories, American sycamore, Shumard oak, southern red oak, white oak, boxelder, green ash, cottonwood, and hackberry. Dogwood, azalea, alder, huckleberries, euonymus, and cane are common in the understory.

ble 32.—*Forest management interpretations for Landtype 28: Upland Flats, Depressions, and Sinkholes with Poor Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Upland oaks	75		57	
Bottomland oaks	90		...	
Yellow-poplar	95		98	
Sweetgum	85		70	
Cottonwood	95		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Moderate to severe	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Cottonwood	Hickories	Hackberry
Shumard oak	White oak	Red maple
Willow oak	S. red oak	Boxelder
Yellow-poplar	Elms	Blackgum
Sweetgum	Green ash	Dogwood
American sycamore		

Description of Landtype 29:
North Slopes

Geographic Setting—Deep, clayey soils on short, steep north-facing slopes between broad undulating uplands and ridges (Landtypes 23 and 24) and terraces and bottoms of permanent streams (Landtypes 31 and 32) or sinkholes and depressions (Landtypes 27 and 28) in Subregion 3. Also included in this landtype are north-facing portions of funnel-shaped sinkholes that have little or no level bottoms. Slope ranges from 10 to 60 percent. Limestone outcrops in places. Soils developed in clayey residuum from cherty limestone and old alluvium. Volume of chert ranges up to 45 percent.

Dominant Soils—Baxter and Cumberland.

Bedrock—Limestone or cherty limestone.

Depth to Bedrock—More than 5 feet.

Texture—Cherty silt loam and silt loam. Silty clay loam and silty clay in severely eroded areas.

Soil Drainage—Well drained.

Relative Soil Water Supply—Medium to high.

Soil Fertility—Moderately high.

Vegetation—White oak, black oak, northern red oak, hickories, yellow-poplar, red maple, and elms; occasional southern red oak, scarlet oak, American beech, bur oak, black walnut, black cherry, white ash, sugar maple, eastern redcedar, shortleaf pine, Virginia pine, and loblolly pine. Dogwood, persimmon, sassafras, and eastern hophornbeam are common in the understory.

Table 33.—*Forest management interpretations for Landtype 29: North Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	80	(65)	123	162
Shortleaf pine	75		136	
Virginia pine	70		92	
E. redcedar	40		...	
N. red oak	90		52->62	
White oak	70			
Yellow-poplar	90		90	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Moderate to severe	Moderate to severe	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Loblolly pine	Bur oak	E. hophornbeam
Virginia pine	Black oak	American beech
Black walnut	S. red oak	Sassafras
White oak	Elms	Red maple
N. red oak	Sugar maple	Dogwood
Yellow-poplar		Persimmon
Black cherry		
White ash		

Description of Landtype 30:
South Slopes

Geographic Setting—Deep, clayey soils on short, steep south-facing slopes between broad undulating uplands and ridges (Landtypes 23 and 25) and terraces and bottoms of permanent streams (Landtypes 31 and 32) or sinkholes and depressions (Landtypes 27 and 28) in Subregion 3. Also included in this landtype are south-facing portions of funnel-shaped sinkholes that have little or no level bottoms. Slope ranges from 10 to 60 percent. South-facing slopes tend to be somewhat steeper and have shallower soils with a higher chert content than north-facing slopes. Limestone outcrops in places. Soils developed in clayey residuum from cherty limestone and old alluvium. Volume of chert ranges up to 45 percent.

Dominant Soils—Baxter and Cumberland.

Bedrock—Limestone or cherty limestone.

Depth to Bedrock—More than 5 feet.

Texture—Cherty silt loam and silt loam. Silty clay loam and silty clay in severely eroded areas.

Soil Drainage—Well drained.

Relative Soil Water Supply—Medium.

Soil Fertility—Moderate.

Vegetation—Black oak, white oak, scarlet oak, northern red oak, southern red oak, hickories, and eastern redcedar; occasional chestnut oak, post oak, bur oak, yellow-poplar, red maple, elms, American beech, white ash, black walnut, black cherry, sugar maple, shortleaf pine, Virginia pine, and loblolly pine. Dogwood, persimmon, eastern hophornbeam, and sassafras are common in the understory.

le 34.—*Forest management interpretations for Landtype 30: South Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index: Natural stands[1]	Site index: Old-field plantations[2]	Average annual growth Cubic feet per acre: Natural stands[3]	Average annual growth Cubic feet per acre: Old-field plantations[4]
oblolly pine	70		104	
hortleaf pine	65		113	
irginia pine	65		70	
. redcedar	35		...	
. red oak	80		62	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight to moderate	Moderate to severe	Moderate to severe	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
hortleaf pine	Hickories	E. redcedar
oblolly pine	Bur oak	E. hophornbeam
irginia pine	Post oak	American beech
lack walnut	Chestnut oak	Sassafras
hite oak	Black oak	Maples
. red oak	Scarlet oak	Dogwood
. red oak	Elms	Persimmon
ellow-poplar		
lack cherry		
hite ash		

Description of Landtype 31:
Terraces and Streambottoms with Good Drainage

Geographic Setting—Deep, silty and loamy soils with good drainage on level to strongly sloping terraces and streambottoms in Subregion 3. Slope ranges from 0 to 12 percent. This landtype occurs below Landtypes 29 and 30 along intermittent and permanent drainages. When Landtypes 31 and 32 are adjacent, Landtype 31 occupies a higher position on the landscape.

Dominant Soils—Elk, Statler, Otwell, and Ashton on terraces, and Nolin, Staser, Huntington, Lindside, and Hamblen on streambottoms.

Parent Material—Mixed alluvium of varying age washed from soils formed in loess and residuum weathered mostly from limestone, and in places, from sandstone, shale, and siltstone.

Depth to Bedrock—4 to 10 feet. Otwell soils have a fragipan at a depth of about 26 inches.

Texture—Silt loam and loam; occasional silty clay loam.

Soil Drainage—Well drained to moderately well drained.

Relative Soil Water Supply—High.

Soil Fertility—Moderate to moderately high.

Vegetation—White oak, sweetgum, yellow-poplar, red maple, northern red oak, hickories, southern red oak, American sycamore, and blackgum; occasional black oak, Shumard oak, cottonwood, elms, American beech, hackberry, black cherry, black walnut, white ash, sugar maple, eastern redcedar, and shortleaf pine. Dogwood, cane, persimmon, euonymus, pawpaw, eastern redbud, and sassafras are common in the understory.

le 35.–*Forest management interpretations for Landtype 31: Terraces and Streambottoms with Good Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
hortleaf pine	75		136	
. red oak	85		57–>62	
hite oak	75			
ellow-poplar	95		98	
humard oak	95		...	
weetgum	80		60	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
ttonwood	Shortleaf pine	E. redcedar
ack walnut	Hickories	American beech
hite oak	Black oak	Sassafras
red oak	S. red oak	E. redbud
umard oak	Elms	Maples
llow-poplar	Hackberry	Blackgum
veetgum		Dogwood
nerican sycamore		Persimmon
ack cherry		
hite ash		

Description of Landtype 32:
Terraces and Streambottoms with Poor Drainage

Geographic Setting—Deep, mostly silty soils with poor drainage on level to gently sloping terraces and streambottoms in Subregion 3. Slope ranges from 0 to 3 percent. This landtype occurs below Landtypes 29 and 30 along permanent and intermittent drainages. When Landtypes 31 and 32 are adjacent, Landtype 32 occupies a lower position on the landscape.

Dominant Soils—Lawrence on terraces and Newark, Melvin, and Dunning on streambottoms.

Parent Material—Mixed alluvium of varying age washed from soils formed in loess and residuum weathered mostly from limestone, and in places, from sandstone, shale, and siltstone.

Depth to Bedrock—More than 5 feet. Lawrence soils have a fragipan at a depth of about 25 inches.

Texture—Silt loam, silty clay loam, and loam.

Soil Drainage—Somewhat poorly drained to very poorly drained.

Relative Soil Water Supply—High to very high.

Soil Fertility—Moderate to moderately high.

Vegetation—Willow oak, sweetgum, pin oak, red maple, blackgum, green ash, and American sycamore; occasional American beech, silver maple, elms, yellow-poplar, cottonwood, hickories, and black willow. Dogwood, cane, huckleberries, and alder are common in the understory.

Table 36.—*Forest management interpretations for Landtype 32: Terraces and Streambottoms with Poor Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Pin oak	95		...	
Yellow-poplar	90		90	
Sweetgum	90		81	
Cottonwood	95		...	
Bottomland oaks	(90)		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight to severe	Moderate to severe	Slight	Slight to moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Cottonwood	Hickories	Black willow
Pin oak	Elms	American beech
Willow oak	Yellow-poplar	Maples
Sweetgum	American sycamore	Blackgum
Green ash		Dogwood

Description of Landtype 33:
Broad Ridges–North Aspect

Geographic Setting–Deep, silty soils on sloping to moderately steep north-facing portions of broad ridgetops and adjoining convex upper slopes in Subregion 3. Surface drainage network is more developed than in Landtype 24. Many small streams drain the area, but sinks and depressions are common. Landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 20 percent. Soils developed in a thin cap of loess over residuum from limestone, interbedded limestone, calcareous shale, and siltstone, or old alluvium. Near the heads of streams there is no level bottom, and this landtype extends down to the stream channel. Further downstream Landtype 35 (north slopes) normally occurs between this landtype and terraces and streambottoms (Landtypes 31 and 32). Volume of chert is 15 percent or less and concentrated in the lower solum below the discontinuity.

Dominant Soils–Crider and Nicholson.

Bedrock–Limestone interbedded with calcareous shale and siltstone in places.

Depth to Bedrock–4 to 13 feet. Nicholson soils have fragipans at depths of 16 to 30 inches.

Texture–Silt loam.

Soil Drainage–Well drained to moderately well drained.

Relative Soil Water Supply–Medium.

Soil Fertility–Moderately high.

Vegetation–White oak, northern red oak, black oak, southern red oak, hickories, red maple, and yellow-poplar; occasional scarlet oak, bur oak, American beech, elms, hackberry, white ash, black cherry, black walnut, sugar maple, eastern redcedar, shortleaf pine, and Virginia pine. Sassafras, dogwood, persimmon, huckleberries, winged elm, sourwood, and eastern hophornbeam are common in the understory.

able 37.—*Forest management interpretations for Landtype 33: Broad Ridges—North Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index: Natural stands[1]	Site index: Old-field plantations[2]	Average annual growth Cubic feet per acre: Natural stands[3]	Average annual growth Cubic feet per acre: Old-field plantations[4]
N. red oak	80		62	
Yellow-poplar	95		98	
Shortleaf pine	80		148	
Virginia pine	80		158	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Black walnut	Shortleaf pine	E. redcedar
White oak	Virginia pine	E. hophornbeam
N. red oak	Hickories	American beech
Yellow-poplar	Bur oak	Winged elm
Black cherry	Black oak	Sassafras
White ash	S. red oak	Maples
	Scarlet oak	Dogwood
	Elms	Sourwood
	Hackberry	Persimmon

Description of Landtype 33:
Broad Ridges–North Aspect

Geographic Setting–Deep, silty soils on sloping to moderately steep north-facing portions of broad ridgetops and adjoining convex upper slopes in Subregion 3. Surface drainage network is more developed than in Landtype 24. Many small streams drain the area, but sinks and depressions are common. Landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 20 percent. Soils developed in a thin cap of loess over residuum from limestone, interbedded limestone, calcareous shale, and siltstone, or old alluvium. Near the heads of streams there is no level bottom, and this landtype extends down to the stream channel. Further downstream Landtype 35 (north slopes) normally occurs between this landtype and terraces and streambottoms (Landtypes 31 and 32). Volume of chert is 15 percent or less and concentrated in the lower solum below the discontinuity.

Dominant Soils–Crider and Nicholson.

Bedrock–Limestone interbedded with calcareous shale and siltstone in places.

Depth to Bedrock–4 to 13 feet. Nicholson soils have fragipans at depths of 16 to 30 inches.

Texture–Silt loam.

Soil Drainage–Well drained to moderately well drained.

Relative Soil Water Supply–Medium.

Soil Fertility–Moderately high.

Vegetation–White oak, northern red oak, black oak, southern red oak, hickories, red maple, and yellow-poplar; occasional scarlet oak, bur oak, American beech, elms, hackberry, white ash, black cherry, black walnut, sugar maple, eastern redcedar, shortleaf pine, and Virginia pine. Sassafras, dogwood, persimmon, huckleberries, winged elm, sourwood, and eastern hophornbeam are common in the understory.

ble 37.—*Forest management interpretations for Landtype 33: Broad Ridges—North Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
N. red oak	80		62	
Yellow-poplar	95		98	
Shortleaf pine	80		148	
Virginia pine	80		158	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Black walnut	Shortleaf pine	E. redcedar
White oak	Virginia pine	E. hophornbeam
N. red oak	Hickories	American beech
Yellow-poplar	Bur oak	Winged elm
Black cherry	Black oak	Sassafras
White ash	S. red oak	Maples
	Scarlet oak	Dogwood
	Elms	Sourwood
	Hackberry	Persimmon

Description of Landtype 35:
North Slopes

Geographic Setting—Deep, mostly silty and loamy soils on sloping to steep north-facing linear and concave midslopes and lower slopes in Subregion 3. Slope ranges from 6 to 30 percent. This landtype usually occurs below Landtypes 23 and 33. When this landtype occurs in association with low narrow ridges (250 feet wide or less), all land up to the crest is included. Landtypes 31 and 32 (Terraces and streambottoms) occur below this landtype. Limestone outcrops occur on steeper parts of this landtype and may be extensive enough to recognize Landtype 11 (Limestone rockland and shallow soils). Chert fragments range from 0 to 15 percent below the lithologic discontinuity in Crider soils. Small amounts of chert are common in the upper solum and increase with depth in Vertress soils. Geodes and pebbles and cobblestones of sandstone or quartzite occur in Waynesboro soils.

Dominant Soils—Crider, Vertress, and Waynesboro.

Bedrock—Limestone interbedded with shale and siltstone.

Depth to Bedrock—5 to 8 feet or more.

Texture—Silt loam, silty clay loam, loam, and fine sandy loam.

Soil Drainage—Well drained.

Relative Soil Water Supply—Medium.

Soil Fertility—Moderate.

Vegetation—White oak, black oak, northern red oak, southern red oak, hickories, yellow-poplar, red maple, and blackgum; occasional scarlet oak, chinkapin oak, bur oak, black walnut, white ash, black cherry, sugar maple, elms, American beech, eastern redcedar, shortleaf pine, and Virginia pine. Dogwood, sassafras, eastern hophornbeam, persimmon, and eastern redbud are common in the understory.

Table 39.—*Forest management interpretations for Landtype 35: North Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Yellow-poplar	90		90	
Black oak	80		≥62	
N. red oak	85			
White oak	80			
Chinkapin oak	80			
Shortleaf pine	75		136	
Virginia pine	75		120	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight to moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Virginia pine	Bur oak	E. hophornbeam
Black walnut	Chinkapin oak	American beech
White oak	S. red oak	Sassafras
N. red oak	Scarlet oak	E. redbud
Black oak	Elms	Maples
Yellow-poplar		Blackgum
Black cherry		Dogwood
White ash		Persimmon

Description of Landtype 36:
South Slopes

Geographic Setting—Deep, mostly silty and loamy soils on sloping to steep south-facing linear and concave midslopes and lower slopes in Subregion 3. Slope ranges from 6 to 30 percent. This landtype usually occurs below Landtypes 23 and 34. When this landtype occurs in association with low narrow ridges (250 feet wide or less), all land up to the crest is included. Landtypes 31 and 32 (Terraces and streambottoms) occur below this landtype. Limestone outcrops occur on steeper parts of this landtype and may be extensive enough to recognize Landtype 11 (Limestone rockland and shallow soils). South-facing slopes tend to be steeper and have shallower soils with higher rock contents than north-facing slopes. Chert fragments range from 0 to 15 percent below the lithologic discontinuity in Crider soils. Small amounts of chert are common in the upper solum and increase with depth in Vertress soils. Geodes and pebbles and cobblestones of sandstone and quartzite occur in Waynesboro soils.

Dominant Soils—Crider, Vertress, and Waynesboro.

Bedrock—Limestone interbedded with shale and siltstone.

Depth to Bedrock—5 to 8 feet or more.

Texture—Silt loam, silty clay loam, loam, and fine sandy loam.

Soil Drainage—Well drained.

Relative Soil Water Supply—Low.

Soil Fertility—Moderately low.

Vegetation—White oak, scarlet oak, chestnut oak, post oak, hickories, southern red oak, and eastern redcedar; occasional bur oak, chinkapin oak, black oak, yellow-poplar, red maple, sugar maple, American beech, Virginia pine, and shortleaf pine. Dogwood, persimmon, sourwood, sassafras, euonymus, winged elm, and eastern redbud are common in the understory.

Table 40.—*Forest management interpretations for Landtype 36: South Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Yellow-poplar	75		63	
Black oak	70		52	
N. red oak	70			
White oak	70			
Chinkapin oak	70			
Shortleaf pine	65		113	
Virginia pine	65		70	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Virginia pine	Bur oak	American beech
White oak	Post oak	Winged elm
Chinkapin oak	Chestnut oak	Sassafras
N. red oak	Scarlet oak	E. redbud
Black oak	Yellow-poplar	Maples
S. red oak		Dogwood
		Sourwood
		Persimmon

Description of Landtype 37:
Broad Undulating Uplands

Geographic Setting—Deep, loamy soils on nearly level to sloping broad uplands in Subregion 3. Slope ranges from 0 to 10 percent but is commonly 6 percent or less, and aspect is not a dominant site factor. Soils formed in 18 to 30 inches of loess over unconsolidated material of sandstone and shale origin. Volume of coarse fragments is 5 percent in the lower solum.

Dominant Soils—Sonora and Gatton.

Bedrock—Limestone.

Depth to Bedrock—More than 5 feet. Gatton soils have a fragipan at depths of 20 to 30 inches.

Texture—Silt loam.

Soil Drainage—Moderately well drained to well drained.

Relative Soil Water Supply—Medium.

Soil Fertility—Moderate.

Vegetation—White oak, southern red oak, black oak, northern red oak, hickories, red maple, and elms; occasional scarlet oak, bur oak, chinkapin oak, yellow-poplar, black walnut, American beech, blackgum, sugar maple, eastern redcedar, and shortleaf pine. Dogwood, persimmon, sassafras, and sourwood are common in the understory.

able 41.—*Forest management interpretations for Landtype 37: Broad Undulating Uplands. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Yellow-poplar	85		80	
Upland oaks	70		52	
Shortleaf pine	70		125	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight	Slight	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Black walnut	Bur oak	American beech
White oak	Chinkapin oak	Sassafras
N. red oak	Scarlet oak	Maples
Black oak	Elms	Blackgum
S. red oak		Dogwood
Yellow-poplar		Sourwood
		Persimmon

Description of Landtype 38:
Broad Ridges—North Aspect

Geographic Setting—Deep, loamy soils on gently sloping to strongly sloping north-facing portions of broad ridges and adjoining convex upper slopes in Subregion 3. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 12 percent. Soils formed in 18 to 30 inches of loess over unconsolidated material of sandstone and shale origin. Volume of coarse fragments is 5 percent or less in the lower solum.

Dominant Soils—Sonora and Gatton.

Bedrock—Limestone.

Depth to Bedrock—More than 5 feet. Gatton soils have a fragipan at depths of 20 to 30 inches.

Texture—Silt loam.

Soil Drainage—Moderately well drained to well drained.

Relative Soil Water Supply—Medium to high.

Soil Fertility—Moderate to moderately high.

Vegetation—White oak, black oak, northern red oak, southern red oak, hickories, red maple, yellow-poplar, elms, and red maple; occasional scarlet oak, American beech, sugar maple, black walnut, black cherry, white ash, bur oak, and shortleaf pine. Dogwood, sassafras, persimmon, sourwood, and eastern hophornbeam are common in the understory.

Table 42.—*Forest management interpretations for Landtype 38: Broad Ridges—North Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Yellow-poplar	90		90	
Upland oaks	75		57	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Black walnut	Shortleaf pine	American beech
White oak	Hickories	Sassafras
N. red oak	Bur oak	Maples
Black oak	Scarlet oak	Dogwood
S. red oak	Elms	Sourwood
Yellow-poplar		Persimmon
Black cherry		
White ash		

Description of Landtype 39:
Broad Ridges–South Aspect

Geographic Setting–Deep, loamy soils on gently sloping to strongly sloping south-facing portions of broad ridges and adjoining convex upper slopes in Subregion 3. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 6 to 12 percent. Soils formed in 18 to 30 inches of loess over unconsolidated material of sandstone and shale origin. South-facing portions of ridges tend to be somewhat steeper and have shallower soils with a higher coarse fragment content than north-facing portions. Volume of coarse fragments is 10 percent or less in the lower solum.

Dominant Soils–Sonora and Gatton.

Bedrock–Limestone.

Depth to Bedrock–More than 5 feet. Gatton soils have a fragipan at depths of 20 to 30 inches.

Texture–Silt loam.

Soil Drainage–Moderately well drained to well drained.

Relative Soil Water Supply–Medium.

Soil Fertility–Moderate.

Vegetation–Scarlet oak, white oak, chestnut oak, post oak, hickories, blackgum, and eastern redcedar; occasional bur oak, black oak, southern red oak, northern red oak, elms, yellow-poplar, sugar maple, American beech, black walnut, black cherry, and shortleaf pine. Dogwood, persimmon, sassafras, sourwood, huckleberries, and winged elm are common in the understory.

Table 43.—*Forest management interpretations for Landtype 39: Broad Ridges—South Aspect. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Yellow-poplar	80		71	
Upland oaks	65		48	
Shortleaf pine	65		113	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Black walnut	Bur oak	American beech
White oak	Post oak	Winged elm
N. red oak	Chestnut oak	Sassafras
Black oak	Scarlet oak	Sugar maple
S. red oak	Elms	Blackgum
Yellow-poplar		Dogwood
Black cherry		Sourwood
		Persimmon

Description of Landtype 40:
North Slopes

Geographic Setting—Deep, loamy and clayey soils on gently sloping to steep north-facing linear and concave midslopes and lower slopes in Subregion 3. Slope ranges from 6 to 30 percent but is usually less than 20 percent. This landtype usually occurs below Landtypes 37 and 38. When this landtype occurs in association with low narrow ridges (250 feet wide or less), all land up to the crest is included. Landtypes 31 and 32 (terraces and streambottoms) occur below this landtype. Geodes, quartzitic pebbles, and sandstone fragments occur throughout the soil mass, but typically increase with depth. As much as 20 percent of the lower solum may be coarse fragments.

Dominant Soils—Riney and Waynesboro.

Bedrock—Soft sandstone and shale.

Depth to Bedrock—4 to 10 feet or more.

Texture—Loam and fine sandy loam.

Soil Drainage—Well drained.

Relative Soil Water Supply—Medium.

Soil Fertility—Moderate to moderately low.

Vegetation—White oak, black oak, southern red oak, northern red oak, yellow-poplar, hickories, red maple, and blackgum; occasional bur oak, scarlet oak, elms, black walnut, black cherry, white ash, sugar maple, American beech, eastern redcedar, and shortleaf pine. Sassafras, dogwood, persimmon, and eastern hophornbeam are common in the understory.

Table 44.—*Forest management interpretations for Landtype 40: North Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
N. red oak	80		57–62	
White oak	75			
Yellow-poplar	90		90	
Shortleaf pine	80		148	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Black walnut	Shortleaf pine	E. redcedar
White oak	Hickories	E. hophornbeam
N. red oak	Bur oak	American beech
Black oak	Scarlet oak	Sassafras
S. red oak	Elms	Maples
Yellow-poplar		Blackgum
Black cherry		Dogwood
White ash		Persimmon

Description of Landtype 41:
South Slopes

Geographic Setting—Deep, loamy and clayey soils on gently sloping to steep south-facing linear and concave midslopes and lower slopes in Subregion 3. Slope ranges from 6 to 30 percent but is usually less than 20 percent. This landtype usually occurs below Landtypes 37 and 39. When this landtype occurs in association with low narrow ridges (250 feet wide or less), all land up to the ridge crest is included. Landtypes 31 and 32 (terraces and streambottoms) occur below this landtype. South-facing slopes tend to be steeper and have shallower soils with higher rock contents than north-facing slopes. Geodes, quartzitic pebbles, and sandstone fragments occur throughout the soil mass, but typically increase with depth. As much as 20 percent of the lower solum may be coarse fragments.

Dominant Soils—Riney and Waynesboro.

Bedrock—Soft sandstone and shale.

Depth to Bedrock—4 to 10 feet or more.

Texture—Loam and fine sandy loam.

Soil Drainage—Well drained.

Relative Soil Water Supply—Low to medium.

Soil Fertility—Moderately low.

Vegetation—White oak, scarlet oak, chestnut oak, post oak, hickories, southern red oak, and eastern redcedar; occasional chinkapin oak, bur oak, American beech, black oak, yellow-poplar, sugar maple, red maple, Virginia pine, and shortleaf pine. Dogwood, persimmon, sassafras, winged elm, and eastern redbud are common in the understory.

Table 45.—*Forest management interpretations for Landtype 41: South Slopes. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
N. red oak	70		48–52	
White oak	(65)			
Yellow-poplar	70		54	
Shortleaf pine	70		125	
Virginia pine	75		120	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Hickories	E. redcedar
Virginia pine	Bur oak	American beech
White oak	Post oak	Winged elm
Black oak	Chestnut oak	Sassafras
S. red oak	Chinkapin oak	E. redbud
Yellow-poplar	Scarlet oak	Maples
		Dogwood
		Sourwood

Description of Landtype 42:
Terraces and Floodplains with Good Drainage

Geographic Setting–Deep, mostly silty and loamy alluvial soils with good drainage on level to rolling terraces and floodplains along the Tennessee River in Subregion 4. Slope ranges from 0 to 12 percent. On floodplains this landtype occurs in stringers paralleling the river in association with Landtype 43, which has poor soil drainage.

Dominant Soils–Wolftever, Sequatchie, Captina, and Statler on terraces, and Egam, Huntington, Bruno, Lindside, Hamblen, and Staser on floodplains.

Parent Material–Mixed alluvium of variable age washed from soils formed in residuum weathered mostly from limestone, sandstone, and shale, and, in places, loess.

Depth to Bedrock–5 to 15 feet.

Texture–Mostly silt loam, silty clay loam, and loam except Bruno, which is sandy loam and loamy sand.

Soil Drainage–Well drained to moderately well drained. Bruno soils are excessively drained.

Relative Soil Water Supply–High. Low areas flood occasionally.

Soil Fertility–Moderately high to high.

Vegetation–White oak, southern red oak, sweetgum, yellow-poplar, blackgum, elms, red maple, and hickories; occasional willow oak, water oak, river birch, American sycamore, American beech, silver maple, black willow, pin oak, hackberry, boxelder, black oak, Shumard oak, cherrybark oak, cottonwood, northern red oak, black cherry, white ash, black walnut, white basswood, loblolly pine, honeylocust, persimmon, sassafras, and water tupelo. Dogwood, cane, hawthorn, sumac, American hornbeam, eastern hophornbeam, American holly, huckleberries, grape, pawpaw, euonymus, bladdernut, and red mulberry are common in the understory.

Table 46.—*Forest management interpretations for Landtype 42: Terraces and Floodplains with Good Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index: Natural stands[1]	Site index: Old-field plantations[2]	Average annual growth Cubic feet per acre: Natural stands[3]	Average annual growth Cubic feet per acre: Old-field plantations[4]
Yellow-poplar	100		107	
Sweetgum	95		93	
Upland oaks	80		62	
Loblolly pine	90		144	
Bottomland oaks	95		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight to moderate	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	Hickories	Black willow
Cottonwood	Black oak	River birch
Black walnut	S. red oak	American hornbeam
White oak	Pin oak	E. hophornbeam
N. red oak	Elms	American beech
Shumard oak	White basswood	Hackberry
Cherrybark oak		Red mulberry
Willow oak		Sassafras
Water oak		Honeylocust
Yellow-poplar		Maples
Sweetgum		Water tupelo
American sycamore		Blackgum
Black cherry		Dogwood
White ash		Persimmon

Description of Landtype 43:
Terraces and Floodplains with Poor Drainage

Geographic Setting—Deep, silty and clayey alluvial soils with poor drainage on level to gently sloping terraces and floodplains along the Tennessee River in Subregion 4. Slope ranges from 0 to 3 percent. On the floodplains this landtype occurs as stringers paralleling the river in association with Landtype 42, which has good soil drainage. Landtype 43 is often wooded, but Landtype 42 is mostly in agriculture.

Dominant Soils—Beason and Robertsville on terraces, and Melvin, Dunning, and Newark on floodplains.

Parent Material—Mixed alluvium of variable age washed from soils formed in residuum weathered mostly from limestone, sandstone, and shale, and, in places, loess.

Depth to Bedrock—5 to 15 feet.

Texture—Silt loam and silty clay loam; occasionally loam.

Soil Drainage—Somewhat poorly drained and poorly drained.

Relative Soil Water Supply—Very high. Soils have a seasonal high water table and are subject to occasional flooding.

Soil Fertility—Moderately high.

Vegetation—Willow oak, water oak, sweetgum, green ash, elms, blackgum, and water tupelo; occasional silver maple, black willow, boxelder, yellow-poplar, American sycamore, loblolly pine, hickories, cottonwood, hackberry, and cypress. Dogwood, cane, grasses, and sedges are common in the understory.

Table 47.—*Forest management interpretations for Landtype 43: Terraces and Floodplains with Poor Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index: Natural stands[1]	Site index: Old-field plantations[2]	Average annual growth, Cubic feet per acre: Natural stands[3]	Average annual growth, Cubic feet per acre: Old-field plantations[4]
Yellow-poplar	90		98	
Sweetgum	90		81	
Bottomland oaks	(95)		...	
Loblolly pine	80		123	
Green ash	90		...	
Cottonwood	100		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Moderate to severe	Moderate to severe	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Cottonwood	Loblolly pine	Black willow
Willow oak	Baldcypress	Maples
Water oak	Hickories	Blackgum
Yellow-poplar	Elms	Dogwood
Sweetgum	Hackberry	
Green ash	American sycamore	
	Water tupelo	

Description of Landtype 44:
Footslopes, Terraces, and Floodplains with Good Drainage

Geographic Setting—Deep, loamy alluvial soils with good drainage on level to steep footslopes, terraces, and floodplains along the Buffalo River in Subregion 4. Slope ranges from 0 to 45 percent but seldom exceeds 25 percent.

Dominant Soils—Minvale, Etowah, and Humphreys on footslopes and terraces, and Ennis, Lobelville, and Cannon on floodplains. All of these soils except Etowah have high chert contents throughout.

Parent Material—Mixed alluvium of variable age washed from soils formed in residuum weathered from cherty limestone and loess.

Depth to Bedrock—5 to 15 feet.

Texture—Cherty silt loam, cherty loam, silt loam, loam, and gravelly silt loam.

Soil Drainage—Well drained.

Relative Soil Water Supply—Moderately high to high. Occasionally flooded in winter and early spring.

Soil Fertility—Moderate.

Vegetation—White oak, southern red oak, sweetgum, yellow-poplar, blackgum, elms, red maple, and hickories; occasional willow oak, water oak, river birch, American sycamore, American beech, silver maple, black willow, pin oak, hackberry, boxelder, Shumard oak, cottonwood, black oak, northern red oak, black cherry, white ash, black walnut, loblolly pine, shortleaf pine, honeylocust, persimmon, and sassafras. Dogwood, cane, hawthorn, sumac, American hornbeam, eastern hophornbeam, American holly, huckleberries, grape, pawpaw, euonymus, bladdernut, and red mulberry are common in the understory.

Table 48.–*Forest management interpretations for Landtype 44: Footslopes, Terraces, and Floodplains with Good Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	90	(55)	144	133
Shortleaf pine	70		125	
Upland oaks	75		57	
Yellow-poplar	95		98	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Loblolly pine	Shortleaf pine	Black willow
Cottonwood	Hickories	River birch
Black walnut	Black oak	American hornbeam
White oak	S. red oak	E. hophornbeam
N. red oak	Pin oak	American beech
Shumard oak	Elms	Hackberry
Willow oak	White basswood	Red mulberry
Water oak		Sassafras
Yellow-poplar		Honeylocust
Sweetgum		American holly
American sycamore		Maples
Black cherry		Blackgum
White ash		Dogwood
		Persimmon

Description of Landtype 45:
Terraces and Floodplains with Poor Drainage

Geographic Setting–Deep, loamy alluvial soils with poor drainage on nearly level terraces and floodplains along the Buffalo River in Subregion 4. Slope is less than 2 percent.

Dominant Soils–Lee.

Parent Material–Young mixed alluvium washed from soils formed in residuum weathered from cherty limestone and loess.

Depth to Bedrock–5 to 12 feet.

Texture–Cherty silt loam and cherty loam.

Soil Drainage–Poorly drained.

Relative Soil Water Supply–Very high. Low areas flood frequently in winter and spring.

Soil Fertility–Moderate.

Vegetation–Willow oak, water oak, sweetgum, green ash, elms, and blackgum; occasional silver maple, black willow, boxelder, yellow-poplar, American sycamore, hickories, cottonwood, hackberry, and loblolly pine. Dogwood, cane, grasses, and sedges are common in the understory.

Table 49.—*Forest management interpretations for Landtype 45: Terraces and Floodplains with Poor Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index: Natural stands[1]	Site index: Old-field plantations[2]	Average annual growth Cubic feet per acre: Natural stands[3]	Average annual growth Cubic feet per acre: Old-field plantations[4]
Loblolly pine	90		144	
Bottomland oaks	90		...	
Yellow-poplar	90		90	
Sweetgum	90		81	
Cottonwood	(100)		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Severe	Severe	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Cottonwood	Loblolly pine	Black willow
Willow oak	Hickories	Maples
Water oak	Elms	Blackgum
Yellow-poplar	Hackberry	Dogwood
Sweetgum	American sycamore	
Green ash		

Description of Landtype 46:
Terraces and Floodplains with Good Drainage

Geographic Setting—Deep, silty and clayey alluvial soils with good drainage on level to strongly sloping terraces and floodplains along the Cumberland, Harpeth, Duck, and Elk Rivers in Subregion 4. Slope ranges from 0 to 15 percent. On floodplains this landtype occurs in association with Landtype 47, which has poor drainage.

Dominant Soils—Pickwick, Armour, Nesbitt, Wolftever, and Capshaw on terraces, and Arrington, Staser, Lynnville, Egam, and Lindell on floodplains.

Parent Material—On terraces, soils formed in 2 to 4 feet of silty alluvium or loess underlain by old alluvium or residuum of phosphatic limestone. Parent material on floodplains consists of recent alluvium washed from soils formed in residuum weathered mostly from phosphatic limestone, cherty limestone, and loess, and possibly from shale and sandstone.

Depth to Bedrock—4 to more than 10 feet.

Texture—Silt loam and silty clay loam; occasionally loam and fine sandy loam. Armour, Capshaw, and Lindell soils contain some chert and gravel.

Soil Drainage—Well drained to moderately well drained.

Relative Soil Water Supply—High. Low areas flood occasionally.

Soil Fertility—High to very high.

Vegetation—White oak, southern red oak, sweetgum, yellow-poplar, blackgum, elms, red maple, and hickories; occasional willow oak, water oak, river birch, American sycamore, American beech, silver maple, black willow, pin oak, hackberry, boxelder, Shumard oak, cherrybark oak, cottonwood, black oak, northern red oak, black cherry, white ash, yellow buckeye, black walnut, white basswood, bur oak, honeylocust, persimmon, and sassafras. Dogwood, cane, hawthorn, sumac, American hornbeam, eastern hophornbeam, American holly, huckleberries, grape, pawpaw, euonymus, bladdernut, and red mulberry are common in the understory.

Table 50.—*Forest management interpretations for Landtype 46: Terraces and Floodplains with Good Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Yellow-poplar	95		98	
Upland oaks	75		57	
Sweetgum	85		70	
Bottomland oaks	85		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate to severe	Slight	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Cottonwood	Hickories	Black willow
Black walnut	Bur oak	River birch
White oak	Black oak	American hornbeam
N. red oak	S. red oak	E. hophornbeam
Shumard oak	Pin oak	American beech
Cherrybark oak	Elms	Hackberry
Willow oak	Yellow buckeye	Red mulberry
Water oak	White basswood	Sassafras
Yellow-poplar		Honeylocust
Sweetgum		American holly
American sycamore		Maples
Black cherry		Blackgum
White ash		Dogwood
		Persimmon

Description of Landtype 47:
Terraces and Floodplains with Poor Drainage

Geographic Setting—Deep, mostly clayey alluvial soils with poor drainage on level to gently sloping terraces and floodplains along the Cumberland, Harpeth, Duck, and Elk Rivers in Subregion 4. Slope ranges from 0 to 5 percent. On floodplains this landtype occurs in association with Landtype 46, which has good drainage.

Dominant Soils—Beason and Forestdale on terraces and Mhoon and Lanton on floodplains.

Parent Material—On terraces, soils formed in mixed fine-textured alluvium washed from watersheds underlain by sedimentary rocks. Parent material on floodplains consists of recent alluvium washed from soils formed in residuum weathered from phosphatic limestone, cherty limestone, and loess.

Depth to Bedrock—More than 5 feet.

Texture—Silt loam and silty clay loam.

Soil Drainage—Somewhat poorly drained and poorly drained.

Relative Soil Water Supply—High to very high. A fluctuating water table is near the surface part of the time, and the landtype is subject to occasional flooding.

Soil Fertility—High to very high.

Vegetation—Willow oak, water oak, sweetgum, green ash, elms, and blackgum; occasional silver maple, black willow, boxelder, yellow-poplar, American sycamore, pin oak, elms, hickories, cottonwood, and hackberry. Dogwood, cane, grasses, and sedges are common in the understory.

Table 51.—*Forest management interpretations for Landtype 47: Terraces and Floodplains with Poor Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Yellow-poplar	90		90	
Bottomland oaks	90		...	
Sweetgum	90		81	
Green ash	85		...	
Cottonwood	95		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate to severe	Moderate to severe	Moderate to severe	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Cottonwood	Hickories	Black willow
Pin oak	Elms	Maples
Willow oak	Hackberry	Blackgum
Water oak	American sycamore	Dogwood
Yellow-poplar		
Sweetgum		
Green ash		

Description of Landtype 48:
Footslopes, Terraces, and Floodplains with Good Drainage

Geographic Setting–Deep, silty and loamy alluvial soils with good drainage on level to strongly sloping footslopes, terraces and floodplains along the Green and Barren Rivers in Subregion 4. Slope ranges from 0 to 20 percent but seldom exceeds 12 percent. On the floodplains, this landtype occurs in stringers paralleling the rivers in association with Landtype 49, which has poor soil drainage.

Dominant Soils–Ashton, Elk, and Otwell on the footslopes and terraces, and Huntington, Nolin, and Lindside on the floodplains. Otwell soils have a fragipan at a depth of about 24 inches.

Parent Material–Soils on terraces developed in old mixed alluvium and those on floodplains developed in more recent mixed alluvium washed from areas dominated by sedimentary rocks.

Depth to Bedrock–5 to 20 feet.

Texture–Silt loam and loam; occasional silty clay loam.

Soil Drainage–Well drained to moderately well drained.

Relative Soil Water Supply–High.

Soil Fertility–Moderately high to high.

Vegetation–White oak, southern red oak, sweetgum, yellow-poplar, blackgum, elms, red maple, and hickories; occasional willow oak, river birch, American sycamore, American beech, silver maple, black willow, pin oak, hackberry, boxelder, Shumard oak, cottonwood, black oak, northern red oak, black cherry, white ash, black walnut, bur oak, honeylocust, persimmon, and sassafras. Dogwood, cane, hawthorn, sumac, American hornbeam, eastern hophornbeam, huckleberries, grape, pawpaw, euonymus, bladdernut, and red mulberry are common in the understory.

Table 52.—*Forest management interpretations for Landtype 48: Footslopes, Terraces, and Floodplains with Good Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
N. red oak	85		>62	
White oak	85			
Yellow-poplar	95		98	
Sweetgum	90		81	
Pin oak	100		...	
Shumard oak	95		...	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate to severe	Slight	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Cottonwood	Hickories	Black willow
Black walnut	Bur oak	River birch
White oak	Black oak	American hornbeam
N. red oak	S. red oak	E. hophornbeam
Shumard oak	Elms	American beech
Pin oak		Hackberry
Willow oak		Red mulberry
Yellow-poplar		Sassafras
Sweetgum		Honeylocust
American sycamore		Maples
Black cherry		Blackgum
White ash		Dogwood
		Persimmon

Description of Landtype 49:
Terraces and Floodplains with Poor Drainage

Geographic Setting—Deep, silty and clayey alluvial soils with poor drainage on level to gently sloping terraces and floodplains along the Green and Barren Rivers in Subregion 4. Slope ranges from 0 to 3 percent. On floodplains this landtype occurs in stringers paralleling the river in association with Landtype 48, which has good soil drainage.

Dominant Soils—Lawrence and Robertsville on the terraces and Newark, Melvin, Karnack, and Dunning on the floodplains. Lawrence and Robertsville have fragipans at depths of 16 to 34 inches.

Parent Material—Soils on terraces developed in old mixed alluvium or residuum from limestone and loess. Soils on floodplains developed in more recent mixed alluvium washed from areas dominated by sedimentary rocks. Karnack and Dunning soils developed in clayey alluvium deposited by slack water.

Depth to Bedrock—5 to 16 feet or more.

Texture—Silt loam, silty clay loam; occasionally loam or fine sandy loam.

Soil Drainage—Somewhat poorly drained to very poorly drained.

Relative Soil Water Supply—High. Floodplains have seasonal high water tables and are subject to occasional flooding.

Soil Fertility—Moderately high to high.

Vegetation—Willow oak, sweetgum, green ash, elms, and blackgum; occasional silver maple, black willow, boxelder, yellow-poplar, American sycamore, pin oak, hickories, cottonwood, and hackberry. Dogwood, cane, grasses, and sedges are common in the understory.

Table 53.—*Forest management interpretations for Landtype 49: Terraces and Floodplains with Poor Drainage. Footnotes appear on page 118.*

PRODUCTIVITY

Species	Site index		Average annual growth Cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Yellow-poplar	90		90	
Bottomland oaks	95		...	
Pin oak	100		...	
Cottonwood	95		...	
Sweetgum	90		81	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Moderate to severe	Moderate to severe	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Cottonwood	Hickories	Black willow
Pin oak	Elms	Maples
Willow oak	Hackberry	Blackgum
Yellow-poplar	American sycamore	Dogwood
Sweetgum		
Green ash		

FOOTNOTES FOR TABLES 5-53

[1] Site indices for each naturally occurring species, except those enclosed in parentheses, are the means o values from soil survey interpretations issued by the SCS for the dominant soils in each landtype (Beck 1962; Broadfoot 1960, 1963; Broadfoot and Krinard 1959; Nelson and others 1961; Schnur 1937; and U.S Forest Service 1929). Estimated site indices are enclosed in parentheses. Base age is 50 years for al naturally grown species except cottonwood, for which it is 30 years.

[2] Adapted from Smalley and Bower's (1971) site curves, base age 25 years.

[3] Annual growth of natural stands calculated from published yields at 50 years: Yellow-poplar — (McCarthy 1933, Table 17), inside-bark volume to a 3.0-inch i.b. top, trees >4.5″ d.b.h.; Sweetgum — (Winter and Osborne 1935, Table 13), inside-bark volume to a 4.0-inch i.b. top, trees >4.5″ d.b.h.; Upland oaks - (Schnur 1937, Table 2, Column 12), outside-bark volume to a 4.0-inch o.b. top, trees >4.5″ d.b.h.; Virgini pine — (Nelson and others 1961, Table 4), outside-bark volume to a 4.0-inch o.b. top, trees >3.5″ d.b.h. 100 percent density; Loblolly and shortleaf pines — (U.S. Forest Service 1929, Tables 44 and 108), tota volume outside bark, trees >3.5″ d.b.h.

[4] Annual growth of loblolly and shortleaf pine plantations calculated from yields at 40 years assumin 1,000 seedlings planted per acre (Smalley and Bailey 1974a, 1974b), outside-bark volume to a 4.0-inch o.b top, trees >4.5″ d.b.h.

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APPENDIX

County Soil Surveys Available for the Western Highland Rim and Pennyroyal[1]

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[1] Asterisk denotes survey that contains a section on woodland suitability.

SMALLEY, GLENDON W.
1980. Classification and evaluation of forest sites on the Western Highland Rim and Pennyroyal. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. S0-30, 120 p. South. For. Exp. Stn., New Orleans, La.

Presents a comprehensive forest site classification system for the Western Highland Rim and Western Pennyroyal-Limestone area in northwest Alabama, west-central Tennessee, and western Kentucky. The system is based on physiography, geology, soils, topography, and vegetation.

Additional keywords: Site index, mean annual increment, soil properties, pines, hardwoods.

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Forest Service
General Technical Report SO-31

Selected Bibliography on Southern Range Management, 1973-1978

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1980

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Selected Bibliography on Southern Range Management, 1973–1978

H.A. Pearson, R.D. Child, E.K. Byington, H.E. Grelen, C.E. Lewis

Committee on Range Bibliography of the Southern Section,
Society for Range Management

Introduction

This bibliography is the fourth of a series inauguated in 1963 for the purpose of recording publicaions that deal importantly with the forest ranges of he South, and with the livestock and wildlife utilizng this vast resource.

For the first number of the series,[1] the compilers ppraised all literature that had accrued through 961. The second bibliography[2] spanned the years 962–1967. The third bibliography[3] covered the ears 1968–1972 and somewhat strengthened the vildlife section with some minor changes. The presnt list contains over 1000 entries and updates the overage of publications through 1978; the present lassification system expands or modifies some preious categories to provide additional attention to nteractions among the various uses of the southern ange. This listing should provide information releant to the diverse interests of land managers, stocknen, conservationists, scientists, teachers, and stuents.

As in the first three bibliographies in this series, he southern range area is considered to extend from astern Oklahoma to Virginia, and from southern Kentucky and Missouri to the Gulf of Mexico. ecause pasture commonly augments the diets of cattle that subsist chiefly on range forage, pertinent publications on supplemental pastures and cropland are included.

The present, 1973–1978, bibliography inaugurates a new production process. Citations collected by WINROCK International Livestock Research and Training Center were used to create a computer-based bibliographic file. This file was edited, corrected, updated, categorized, and indexed by a team of range scientists (the authors), editors, librarians, technical information specialists, and computer specialists. For the most part, team members worked together from their own offices by using various communication channels—many computer-based—to achieve the joint effort described above. The publication appears to be similar to earlier bibliographies in this series, but the author index, the keyword index, the computer typesetting, and camera-ready copy were drawn from the corrected computer-based file records as by-products—requiring little additional effort.

Another by-product is a searchable data base. The records from the computer file are now part of CORR (Communications on Renewable Resources), an information resource available for searching through Bibliographic Retrieval Services, Inc. (BRS). Access to CORR may be obtained through Richard L. Knox, Leader, Technology Transfer Group, Forest Service, U.S. Department of Agriculture, Box 2417, Washington, D.C. 20013. Development of this and other subsets of CORR relevant to range management have been sponsored jointly by the Interagency Range Information Committee. Cooperation by the Forest Service (Vern L. Thompson, Don D. Seaman, Theodore V. Russell), the Soil Conservation Service (Donald T. Pendleton, Douglas V. Sellars) of the U.S. Department of

---

[1] Campbell, R.S., L.K. Halls, and H.P. Morgan. 1963. Selected ibliography on southern range management. USDA Forest ervice Research Paper SO–2, 62 p. Southern Forest Experiment ation, New Orleans, Louisiana.

[2] Duvall, V.L., A.W. Johnson, and L.L. Yarlett. 1968. Selected bliography on southern range management, 1962–1967. USDA orest Service Research Paper SO–38, 34 p. Southern Forest xperiment Station, New Orleans, Louisiana.

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Henry A. Pearson is Chief Range Scientist and Harold E. Grelen is Principal Range Scientist at the Southern Forest Experiment ation, Forest Service—USDA—Pineville, Louisiana. R. Dennis Child and E. K. Byington are Range Scientists at Winrock ternational Livestock Research and Training Center, Petit Jean Mountain, Morrilton, Arkansas. Clifford E. Lewis is Principal Range ientist, Southeastern Forest Experiment Station, Forest Service—USDA—Marianna, Florida.

Agriculture and the Bureau of Land Management (Ron Younger and Edward L. Fisk) of the U.S. Department of the Interior has made the Committee's work possible. Mary B. O'Hara, Forest Service Technical Information Specialist, has provided leadership and direction in developing the concept of CORR and CORR products. Cooperation between the Forest Service and the U.S. Department of Energy has provided valuable computer services, particularly use of ORCHIS, a system developed at Oak Ridge National Laboratory.

Sources consulted included books, periodicals, publications of the U.S. Government, and of State Agricultural Experiment Stations, releases of regional organizations and private foundations, and bibliographies with abstracts. Periodicals searched included:

Agronomy Journal
American Forests
American Journal of Botany
American Midland Naturalist
Botanical Gazette
Botanical Review
Crop Science
Ecology
Ecological Monographs
Economic Botany
Forest Farmer
Forests and People
Forest Science
Gulf Coast Cattleman
Journal of Animal Science
Journal of Forestry
Journal of Range Management
Journal of Soil and Water Conservation
Journal of Wildlife Management
Soil Science
The Cattleman

Several members of the Society for Range M agement and State and Federal agencies reviev an initial draft of the bibliography and suppl additional pertinent references and suggestions:

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Range Plants

GENERAL

eneral phases of southern range vegetation.

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THE CROSSETT STORY

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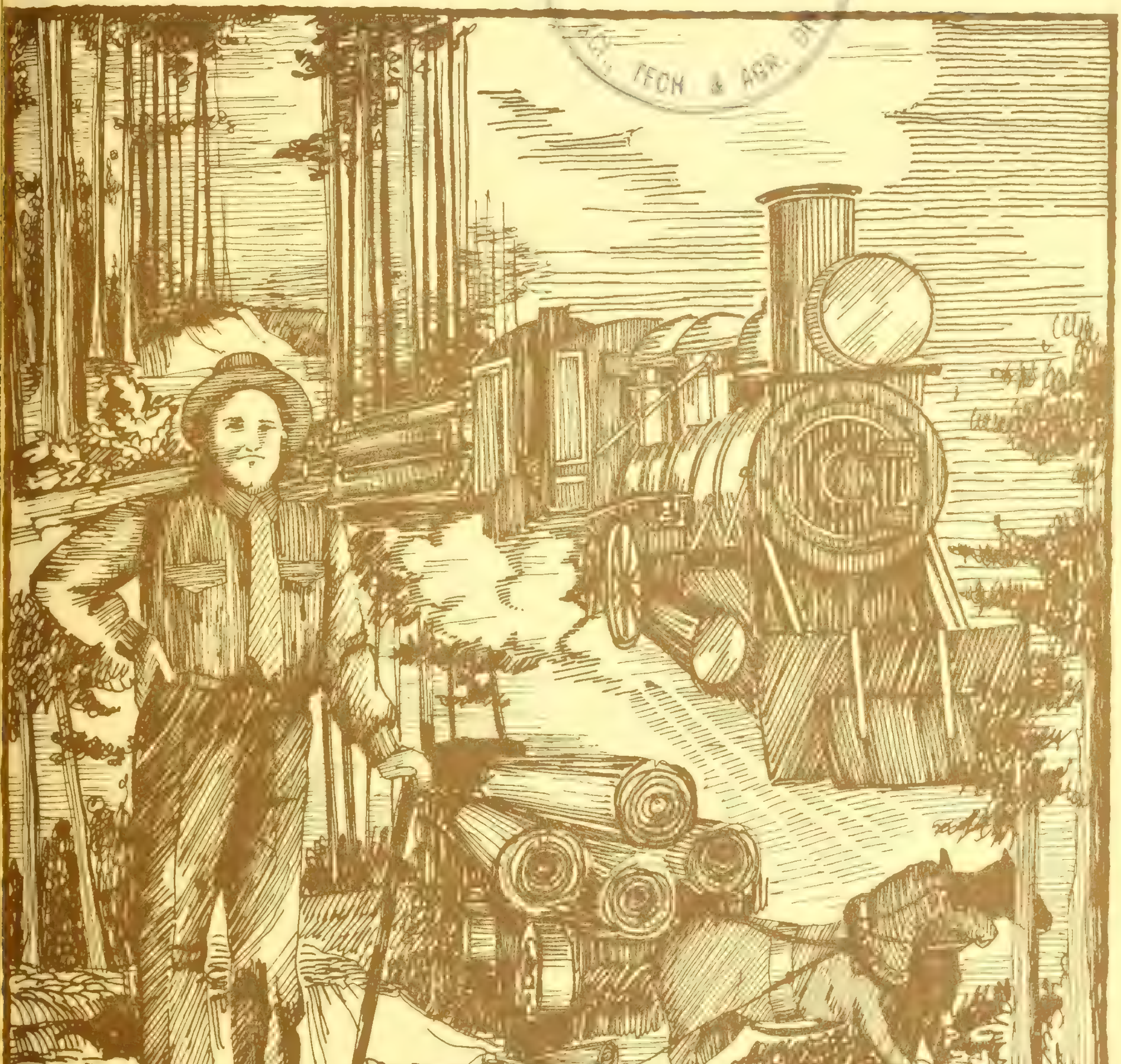
The Beginning of Forestry in Southern Arkansas and Northern Louisiana

R. R. Reynolds



U.S. Department of Agriculture
Forest Service

Southern Forest Experiment Station

General Technical Report SO-32

1980

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THE CROSSETT STORY

The Beginning of Forestry
in
Southern Arkansas and Northern Louisiana

R. R. Reynolds

Southern Forest Experiment Station

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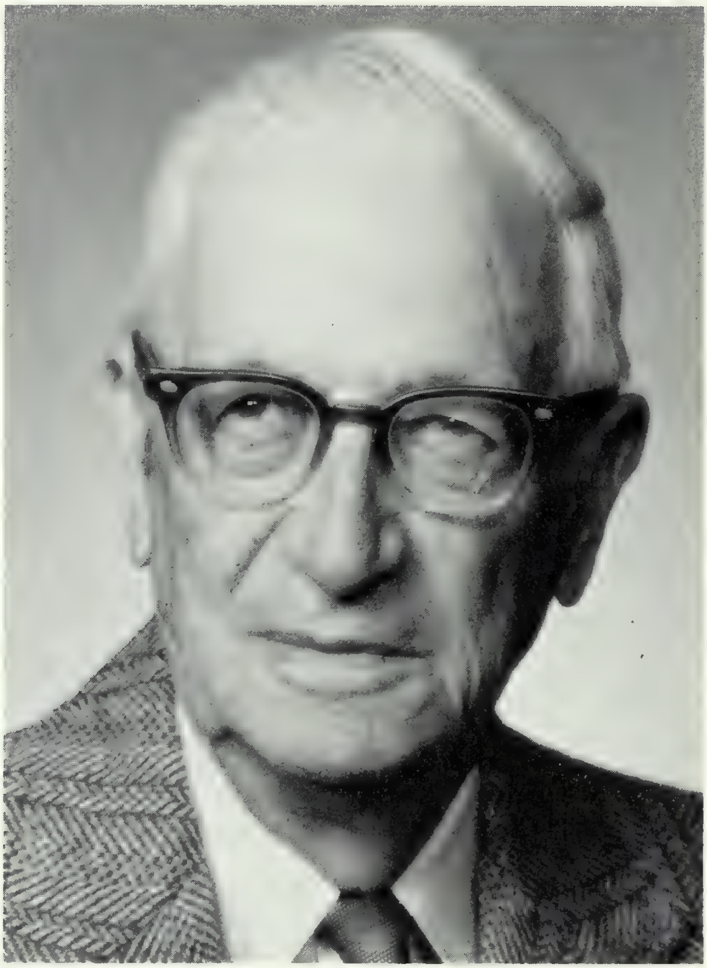
I would like to give special thanks to A. E. Wackerman, who was Chief Forester for the Crossett Lumber Co. from 1927 to 1932 and who was a member of the staff of the Southern Forest Experiment Station when my work at Crossett began. He provided much encouragement and guidance to me during those early years and for many years after.



R. R. Reynolds was born on December 21, 1906 near Howard City, Michigan. He graduated from the University of Michigan Forestry School with a B.S. in 1929 and an M.S. in 1930.

In July 1930, he joined the Southern Forest Experiment Station. He spent his first 3 years with the Station working on county Forest Economic Studies, and on case studies of individual companies. In 1933, the Crossett Experimental Forest opened, and Reynolds spent the next 34 years establishing and directing the research center. He is author or co-author of about 175 publications.

Reynolds retired from the Forest Service in 1969, but he has remained active in the forestry field, as a member of the Society of American Foresters and as a practicing tree farmer.

PREFACE

This brief history describes some of the more important forestry and related happenings in southern Arkansas and northern Louisiana between 1930 and 1955. This was the period in which clearcutting of the virgin pine timber came to a crashing halt—because there was no more. It also marked the start of managing the second-growth stands at a time when no one knew how or why they should be managed. These stands, which had grown up in spite of no protection or management, were generally understocked and widely variable in age classes. To confound the problem, it was a universal belief that lumber from second-growth trees was practically worthless.

The account is largely limited to the shortleaf-loblolly pine-upland hardwood forests of southern Arkansas and northern Louisiana because the writer of these notes grew up with (in a professional sense) and knew this area intimately. For the same reasons, the story is centered on Crossett, Arkansas, and on holdings of the Crossett Lumber Company.

Many other areas and forest ownerships have equally interesting histories, but foresters and managers in the Crossett area were leaders in the changeover from virgin to second-growth timber management and operation in the South. A great many "firsts" were hammered out here. And for 40 years, people from around the country—and the world—came to Crossett to see the far-reaching developments. They learned how they might put the same practices in use on their own areas and forests.

THE CROSSETT STORY

The Beginning of Forestry in Southern Arkansas and Northern Louisiana

R. R. Reynolds

IN THE BEGINNING— "CUT OUT AND GET OUT!"

Sawmilling of the virgin shortleaf and loblolly pne timber in southern Arkansas and northern Luisiana began on a large scale in the 1890's. Mlls cutting upward of 50,000 bd. ft. per day were cmmon, one was located 30 to 40 miles or so in eery direction. Because of the many logs needed eery day and the fact that logging trucks were uheard of, all large-scale logging was done by rilroad. Generally, two spurs were constructed c the main-line into each 40-acre area, and teams c oxen or horses were used to skid the logs to the surs. Here logs were picked up, by steam-cerated loaders that ran on rails on top of the log crs, and placed on the log cars for transportation t the mill (fig. 1).

Although some stands of timber had as much a 25,000 bd. ft. (Doyle) per acre, the average that ws usable, by standards in use at the time, was aout 7,000 bd. ft. (fig. 2). This was according to Ivi Wilcoxon, longtime logging and woodlands Sperintendent of the Crossett Lumber Company c Crossett, Arkansas.

In any event, by the middle to late 1920's, the ed of the big cut was near at hand, and by 1930 mny of the mill-owners, who had come South aer logging in the Lake States had been compted, started looking at the big untapped virgin snds of the West as the location for their next cerations.

Many families had moved into the uplands of southern Arkansas and northern Louisiana, had homesteaded, and had established farms many years before the coming of the big sawmills. To these farmers, trees were something that had to be disposed of by cutting and burning before the areas were suitable for row crops. Since machinery for such operations was not available in those days, the farmers often welcomed the big sawmillers with open arms. According to an oft

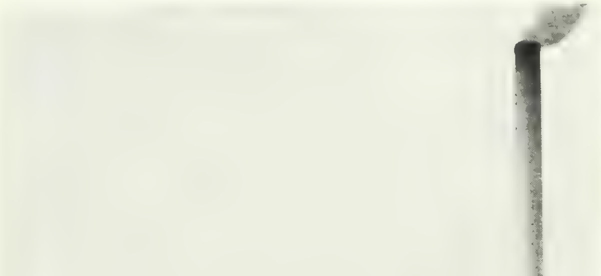


Figure 1.-Sawmill #1, power plant, log pond, and log ramp of Crossett Lumber Co. Mill housed two high-speed band mills. (FS 394380).

repeated story, the Crossett Lumber Company people set up a land office at the county seat in Hamburg, Arkansas, and offered $2.50 per acre in hard cash, for the farmer's timber or timberland. When word of this got out, small timberland owners by the hundreds hurried in to get rid of their extra land or timber before those "Damn Yankees ran out of the stuff."

In other words, as late as 1933 many people thought that timberland (or areas with trees) was wild and undeveloped land. It would be of real value only when the trees were cleared and the acres put into pasture or row crops.

When logging of the virgin timber began on a large scale, no one thought about developing the second-growth stands. Only one kind of lumber was worth anything for construction purposes: slow growth virgin. Second-growth trees were often rapid growth, and second-growth lumber was supposed to be practically worthless "because it would warp or shrink or twist." And it supposedly had very little strength. So even though the lumber companies only cut trees that were about 14 inches and larger in stump diameter they made no attempt to keep the smaller pines and hardwoods from injury. Many of those were cut and used for ballast and rough ties for the spur logging railroads.

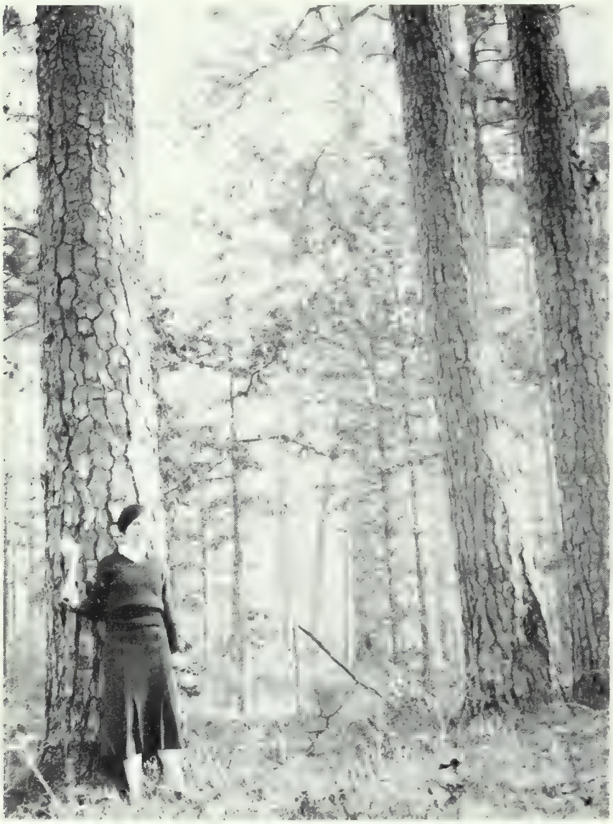


Figure 2.- Virgin loblolly-shortleaf pine-upland hardwood stand near Crossett, Ark., in 1934. Some of the larger trees were 34 to 36 inches in diameter. The young woman pictured is Christine Hendrix (Mrs. A. G. Jacobson).

It was also a certainty that once the pine "slashings" had dried out they would catch fire and a nice hot burn would kill a large proportion of these smaller seedlings, saplings, and poles.

Because of this and because there was no organized attempt to protect the woods from fire it now seems amazing that many of the smaller pine trees came through the fires, began to grow at a rapid rate, and began to produce seed Seedlings sprang up and some thin, but respectable, young pine stands with trees of many diameters developed on many of the areas that had been cut over 10 to 20 years previously.

Hardwoods, from sprout size up to about 20 inches d.b.h. (diameter breast high), had always been intermingled with the pine in virgin stands Since such hardwoods had little or no value at the time, the ones that were not seriously damaged in the cutting of the big pine stands continued to grow and reproduce. So the new, young pine stands often contained as many or more hardwoods than pine—and many of these hardwoods were larger than the pine.

PROFESSIONAL FORESTRY COMES TO CROSSETT

For the few companies in the South that did not fold up when the virgin timber neared an end the decision to manage their second-growth forest for timber production was a gradual one, evolving as a last resort. The Crossett Company was no exception.

Until about 1930, the Crossett Lumber Company continued to offer its cutover land for sale to farmers and others. The company also tried raising cattle on an experimental basis. It was decided that something of better grade than usual "range" cattle should be produced, so the company purchased a high-quality and very expensive bull from Iowa in order to improve the strain. The idea was good but the bull could not stand the ks and the heat. The story was told that in hot ather they had to put him into a padded cell in barn, with fans blowing on him from "before" d "aft."

Two areas were included in the cattle venture. e was located about a mile east of Crossett on Unity Road (now U.S. Highway 82). The other a was at the northern end of the Prairie Du tte in Louisiana. The cattle venture failed, but 1927 some of the old Cattle Farm area east of ssett was planted with pine trees. This was the st sizeable loblolly pine plantation in the area g. 3).

ure 3.-Crossett Lumber Co.'s cattle farm plantation of loblolly pine. Stand was 14 years old at the time of the photograph.

Having tried in vain to find suitable uses for i "cutover," the Crossett Company probably s in a receptive frame of mind for most any idea en Prof. H. H. Chapman entered the picture. of. Chapman, who headed up the annual Yale iversity summer camp for forestry students at ania, Louisiana, became interested in some of second-growth stands that had developed on Crossett Company holdings. With the aid of ne of his students, he inventoried some of these as and suggested that perhaps the Company ld make a second cut of logs on some locations e the cutting of the virgin timber had come to end. In any event, he undoubtedly was ponsible for creating an interest in "timber sibilities" in the minds of the owners of the ssett Lumber Company.

The interest was great enough for Company officials to agree to the appointment of a professional forester, W. K. Williams, who over considerable opposition in 1926 and early 1927 put through a proposal to start leaving pine seed trees (called "mammy trees" by the saw crews) at the time the virgin timber was being cut. He also began trying to interest the local people in fire protection for the woods. This latter proposal was of mountainous proportions because all the folks knew that the woods had to be burned over every few years "in order to kill the snakes and the ticks" and to "green up the grass."

Williams resigned from his position after about a year to become Extension Forester in the Washington Office of the Department of Agriculture. He was replaced in March 1927 by A. E. (Wack) Wackerman, who was a forestry graduate of the University of Minnesota and of Yale University (fig. 4). According to Wack, he

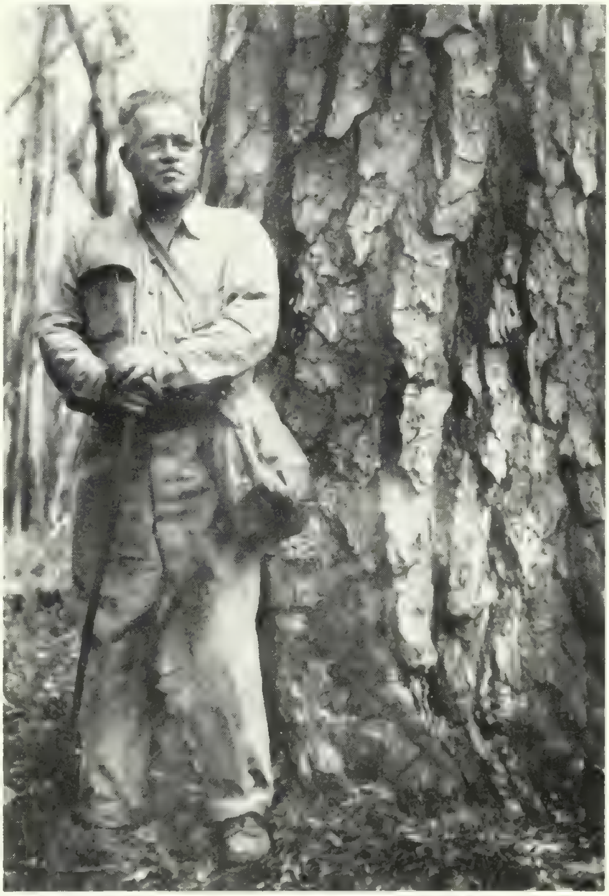


Figure 4.-A. E. (Wack) Wackerman, second forester for the Crossett Lumber Co. Wack had much to do with the successful adoption of forest management for the Company's stands.

[illegible] to work under the general direction of Prof. R. C. Bryant of Yale University, who had been employed as consultant in forestry matters by the Crossett Company. He was to correlate his work with Levi Wilcoxon, who at the time was logging superintendent. Levi had foreseen the need for fire protection on company timberlands and had built five firetowers in strategic locations on Company lands. These had been connected with a telephone system. Wack reported that the towers were "in, but not working because no one had ever had experience or training in fire protection before." Thus, one of his first major jobs was to set up a fire protection system and to get it working. His second big assignment was to carry out a cruise of two of the blocks of older cutover lands to determine: (1) the amount of second-growth pine and hardwood present, (2) growth and mortality, and (3) the amount of virgin timber remaining. He would then prepare possible management and cutting plans.

THE U.S. FOREST SERVICE COMES TO CROSSETT

When I joined the Southern Forest Experiment Station in July, 1930, fresh out of the University of Michigan School of Forestry, many of the large southern mills had closed and more were closing every month. The production of lumber had been largely taken over by small, "peckerwood" mills that could be easily moved from place to place, and logging could be done by two or three pairs of mules or horses. It was agreed almost universally that the South would soon be out of the large volume, large-sawmill business, and few had any idea as to what would, or should, happen to the "cutovers."

Because of this situation, the Southern Station's economics division, to which I was assigned, was devoting most of its time to "Forest Economics Studies." The objective was to inventory the timber and timberland in a county, determine the growth possibilities, estimate the amount of abandoned farmland that could be planted to trees, assess the volume of forest products still being produced, and approximate when the remaining sawmills and other wood-using plants would run out of raw material and have to close.

The Station also felt that one of its mai thrusts should be to attempt to help save as man of the forest industry operations as possible. Thi included cooperative agreements with industrie to help inventory various company forests (whe invited to do so); to help work out managemen plans; to do mill-scale and other research studies and to determine what kind of logs could b profitably handled by the existing utilizatio plants. These agreements were called "Cas Studies." It was felt that results from one stud could be used by other companies or timberlan owners with similar type stands and problems

The first Case Study was with the Ozark Badger Lumber Company at Wilmar, Arkansas Information was gathered on volumes of mer chantable pine and hardwood per acre and dat needed for local volume tables were compiled Information on annual growth and mortality wer computed. Most important, a plan of managemen was suggested that would allow a harvest of log for the company sawmill, at the same time tha the growing stock on the company's forests woul be gradually improved and increased. The ob jective was to help show how it might be possibl for this company not only to stay in business bu to increase the production of logs, lumber, an other products on a sustained yield basis.

Field work on the Ozark-Badger case study undertaken during the period of April 27 to Ma 20, 1932, was largely performed by Art Spiller and myself. Assistance was given by Jame Daniels, who was mill and logging superintenden of Ozark-Badger, and by L. K. Pomeroy, co-owne of the company, who was later to become famou as a timberland owner and forestry consultant Overall supervision of the work was by I. F Eldridge, head of the economics division staff.

Meanwhile, effects of the great depression tha started in 1929 were being felt by the souther pine lumber industry generally. Both price an demand for lumber dropped alarmingly. Th Crossett Lumber Company, among many, move to meet the challenge to their existence by cuttin costs drastically, including salaries of thei forestry personnel, by 50 percent. This did no stop the balance sheet from showing red ink, an in desperation the Company management cu some salaries, including Forester Wackerman's by another 50 percent a year later.

After such drastic reductions in salary Wackerman was more than willing to accept a offer of employment on the staff of the Souther tation, and he was assigned to the economics ivision. He made the transfer early in 1933 and as headquartered in New Orleans.

Wackerman's previous inventories of the older econd-growth stands at Crossett had indicated hat the Company might be able to continue awmill operations on a reduced scale if it made ome radical changes in operating policy. Because imber from fast growing second-growth shor- eaf-loblolly pine was not readily saleable, ackerman had thought that Crossett might stretch out" the cut of the last 25,000 acres of irgin, culled virgin, and advance second-growth imber. They could then have, for several years, ome "cream" high-grade lumber from the virgin ands to go along with the "skim-milk" lumber om the second-growth.

As was mentioned earlier, the Forest Service as willing and anxious to assist any timberland wner who was interested in working toward ustained yield production of forest products. And e Crossett Company seemed a fine example of a mpany that might well benefit from cooperation ith the Government. Thus came about the cond case study the station undertook to help rivate industry attempt to move into the entirely w second-growth forestry or forest management ld.

The Southern Station entered into a operative agreement with the Crossett Com- any, under which the station would provide chnical personnel to mark one or more com- rtments of the remaining 25,000 acres men- oned above, known as the "East Block."

Before leaving the Crossett Lumber Company, ackerman had cruised this East Block area, had ade a growth study, and had prepared volume bles for the virgin and advance second-growth ands. He had determined that, if the 25,000 res was divided into 10 blocks of about 2,500 res each, one block could be cut each year on a ght selection cutting basis, and would yield from to 10 million bd. ft. of logs. Growth would be ch that 10 years hence the merchantable volume ould have grown back to the original amount d another cut could be made.

I was chosen to handle this marking job and I rived, with my wife Geneva, in Crossett on ugust 13, 1933. Field work started immediately, preliminary arrangements had been made to e five boys from a local Civilian Conservation orps (CCC) camp. Because this was the first rge-scale marking of timber on a selection basis in the region, we decided to keep more detailed records than would normally be required. All cut and leave trees were measured, and cut trees were marked with paint at the time of measurement. The record was by one-inch diameter classes, and the tally was by diameter and number of 16-foot logs.

It might be of interest to note that the strictly virgin timber was marked to a guiding diameter limit of 24 inches and oldfield timber to 17 inches. These limits were flexible, however, and any trees below these limits were marked for cutting if defective or very limby, or if the stand needed thinning in a particular spot. Fast growing and high-quality trees above these limits were left to compensate for the trees below the limits that were taken. Marking of the first unit was completed November 10, 1933.

THE BEGINNING OF SELECTIVE CUTTING AND MANAGEMENT

As the end of the virgin timber approached throughout the region, nearly all concerned with logging agreed that railroads just could not be used for logging the second-growth stands. At least 2,500 bd. ft. (Doyle) of logs of good size would have to be cut per acre to make it pay. The relatively small size of the second-growth logs would cause the costs per thousand board feet to soar. Furthermore, only a few of the trees in the many-diametered, natural second-growth stands were large enough to cut for logs. Seemingly, what was needed was a system of stand management and harvesting that would allow light cuts per acre and, at the same time, permit the remaining trees to develop into merchantable sizes. This pointed to the need for trucks.

Although they were very crude compared to today's models, a few trucks were being used by a few small mills. Could trucks be depended upon to produce a reasonable volume of logs for the large mills? And could such transportation be used for light harvests in second-growth stands?

The Southern Station was interested in this problem because it was a common one for nearly all mills in the South in the early 1930's, but the station had no funds for undertaking such a study. I was encouraged to apply for cooperative funds from the Charles Lathrop Pack Foundation

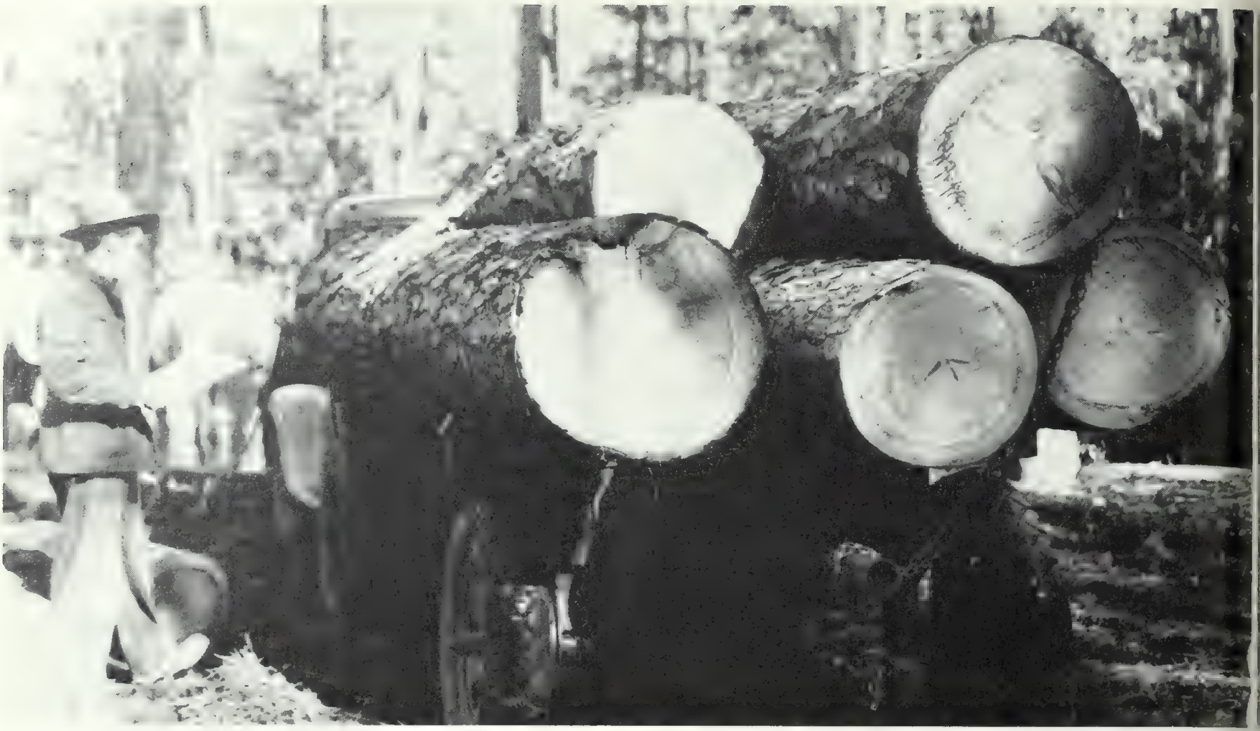


Figure 5.-A truckload of pine logs produced on the Charles Lathrop Pack Selective Logging Study area near Fountain Hill, Ark. Note the 32 in. x 6 in. high pressure tires and the team of horses hitched to the front of the truck to help it out of the woods. CCC crewman was keeping records on volume per load and time required for loading and hauling.

for a "Selective Logging Study," which was approved in the late summer of 1934. Second-growth natural shortleaf-loblolly pine-hardwood stands owned by the Crossett Lumber Company were used for the study. The objective was to selectively log blocks of timber that had been marked for the removal of various volumes of pine and hardwoods, and determine the costs of felling, skidding, loading, hauling, and sawmilling.

The selected area was located about 5 miles southwest of Fountain Hill, Arkansas. Work on survey of block boundary lines and inventory of stands began September 5, 1934.

The trucks were gasoline powered and were used in combination with small two-wheel trailers (fig. 5). Both truck and trailer were equipped with 32 in. x 6 in., high-pressure tires. Loading was cross-haul with horses.

On November 5, 1934, with help from our five-man CCC crew, I began marking trees in the first block to be logged near Fountain Hill. To learn time-study techniques and work out procedure problems, we chose a fairly old "oldfield" stand that was marked for a rigid 17-inch diameter limit harvest.

Trees and logs were cut with cross-cut saws, skidded a short distance to truck-loading points by horses and loaded by horse cross-haul onto trucks. They were then transported to a large log storage area on the company's A.D.&N. Railroad (Ashley-Drew and Northern Railroad, locally known as the "All-Day And Night Line" because it usually took all day and part of the night for the train to make a round trip from Crossett to Monticello, Arkansas, a distance of 45 miles) (fig. 6).

As soon as all the logs—they had to be produced in 1934 before the winter rainy season started—had been cut they were loaded on railroad log cars and transported to the mills in Crossett for mill cost and lumber out-turn studies.

Each log was marked with tree and log number and time cost studies were made of each stage of the operation. Lumber out-turn, grade, and value were computed for each log and each tree. Thus, it was possible—after the field work and sawmilling were completed in 1935—to summarize costs and returns for trees of various sizes and for the amount cut per acre from the various test plots.

On October 1, 1935, field work on the main part of the study got underway. On this portion we planned to cut, on an improvement selection asis, about 2,000 bd. ft. (Doyle) of pine and ,000 bd. ft. of hardwood per acre from 40 acres; ,000 bd. ft. of pine only per acre from 80 acres, nd 500 bd. ft. of pine only per acre from 80 acres. ll logs would be numbered and handled as efore, and time studies of all phases of the peration would also be made as before.

The field work was completed November 25, 936. Although the analysis of the mass of inormation obtained and the final report would not e completed for about 2 years, much very aluable information was available. Since this was he first study of its type in the country, the emand was great for tables, data, and articles of ll types. Among these was a local volume table r second-growth, natural shortleaf-loblolly pine y d.b.h. and log length. This was probably the rst such table for the South. A local board-foot olume table for second-growth upland-ardwoods was also produced. Data on yield by rade of lumber obtained from the second-growth rees and logs of various sizes were in great emand. Data on cutting, skidding, loading, and auling costs for second-growth shortleaf and blolly pine stands cut on a selection basis were lso of great interest to many foresters and mberland owners interested in future forestry ventures. Many special compilations of data were made for many people and several articles on the general subject of "Good Lumber From Second-Growth Southern Pine" and "Good Forestry is Good Business" were written. And at the same time, we were covered up with visitors who were interested in details of the method of timber inventory, determination of allowable cut, and marking procedures for second-growth pine stands to be managed under the selection basis.

The final report on the Pack study found that small logs (8-inch to 10-inch top diameter and up to 18 feet long) of all grades and #3 and #4 logs (rough and knotty) of up to 16-inch top diameter were costing a company (such as Crossett) much more than they were realizing from the lumber produced therefrom. The study also indicated that, if the logs were of reasonable size and grade, it would be profitable to selectively log as little as 750 bd. ft. (Doyle) per acre. Further, if dense spots of small trees were thinned for pulpwood and most of the hardwoods about 4 inches and larger could be removed for logs, or acidwood, or were girdled, the lightly stocked second-growth stands could be put into fine shape for future management and growth.

igure 6.- Crossett Lumber Co. log train with a load of second growth shortleaf-loblolly pine and hardwood logs from the Pack Selective Logging Study. (FS350903).

THE CROSSETT RESEARCH CENTER AND EXPERIMENTAL FOREST

Before the marking of the first unit of the East Block was completed in 1933, the Crossett Lumber Company offered the Forest Service an area of about three sections of second-growth timberland to be used as an Experimental Forest and Research Center. Location could be anywhere on the company's holdings. So my notes for Friday, September 29, 1933, say, "Began looking over timberland for a proposed Experimental Forest." Wackerman joined in this search on October 14 and 15. And, starting on October 18, 1933, Director Demmon of the Southern Station looked over some of the possible areas (fig. 7).

After final decision on the Experimental Forest location was made, first work of running out boundary lines was started on October 21, 1933. Before this, the Southern Station had carried on old-field pine growth and yield studies in cooperation with the Urania Lumber Company

Figure 7.-E. L. Demmon, Director of the Southern Forest Experiment Station at the time that the Crossett Research Center was established.

at Urania, Louisiana, and considerable work on planting and spacing of southern pine at Bogalusa, Louisiana, in cooperation with the Great Southern Lumber Company. The station also had research on naval stores production and problems underway at Lake City, Florida. But the Crossett Research Center was to be the first U.S. Forest Service branch research station in the South.

The area to be developed into the Crossett Experimental Forest contained mainly natural stands of shortleaf and loblolly pine that had developed unaided since the virgin timber had been cut to a 14-inch stump diameter limit in 1915. Stocking varied greatly from acre to acre from none to perhaps 5,600 bd. ft. (Doyle). Since little or no hardwoods had been cut at the time of the virgin-timber removal, nearly every acre had hardwoods ranging in size from new reproduction up to trees that were 24 inches in diameter. Many of the big hardwoods were post oak that had been in the virgin stands.

The Crossett Lumber Company gave the Forest Service 1680 acres of timberland outright. They reserved the timber but offered the Government a deal: if the station should return to the company in 20 years a volume of timber equal to the volume on the area at the time of the agreement, the land and the remaining timber would become the property of the Government.

By the end of 1933, it was agreed by the Director of the Southern Station that: (1) much of the early research would be on ways and means of improving and rebuilding the previously unmanaged second-growth stands, (2) the economics branch of the station would, working under the station director, have general control of development of the research facility, and (3) the day to day development and operation of the branch station would be under my direction.

We soon agreed that, to have good fire protection for the area as well as provide ready access for research purposes, roads should crisscross the area at about half-mile intervals. To do this without funds was the trick.

At the end of 1933, work projects were being organized by the Government in order to give employment to some of the unemployed in the area around Crossett. The station applied for a Civilian Work Project (C.W.P.) for the road work, and this was approved December 16, 1933. Mr. Wilcoxon, logging superintendent of the Crossett Lumber Company, offered us three of his logging camp supervisory force and Ike Rawls, one of the camp log scalers who was to become timekeeper, scaler, and in charge of tools. Ike soon became my valued assistant, and he helped on the installation

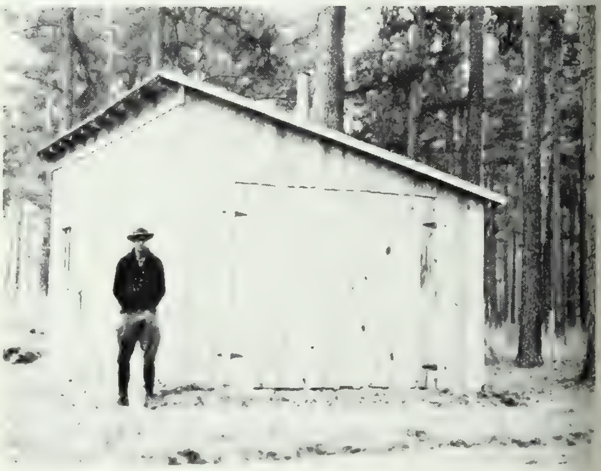


Figure 8.-First building of the Crossett Experimental Forest and Research Center. Building was used as tool shed and office until permanent office and other buildings were constructed. Building was built in December 1933. Russ Reynolds shown by building.

nearly every research study over the next 40 ears.

We began building a temporary shed and fice on December 22, 1933, and started sur- ying and staking road lines (fig. 8). Also a nique feature of the road construction was that machinery was available for the job—and none as wanted by the C.W.P. officials. The objective as to make use of the maximum amount of anpower. Thus we planned to build the roads tirely by hand—with shovels, picks, and axes. oads were built 20 feet wide from ditch to ditch. e cut trees in the right-of-way flush with the ound and threw dirt dug from the ditches ward the center of the roadway in order to cover the stumps (fig. 9).

Men were selected from relief rolls from the ossett area and from as far away as Stillion on e Saline River, where the closing of a mill had stranded several families. Conditions were so serious that the Stillion group had to walk 8 miles down the Rock Island railroad to Crossett each morning, leaving Stillion at about 4 a.m. We would pick them up at the Crossett Filling Station at 7 a.m. each day. The men would put in a 10-hour day. Then we transported them back to Crossett, and they walked the eight miles back to Stillion. They would arrive at Stillion at about 9 p.m. Here their families would have some eats ready for them. They would later fall exhausted into bed. Their wives would awaken them at 3 a.m. and they would start another long day. For all of this the men were paid $1.25 per day for a 4-day week.

Among the Stillion group was a black man by the name of Jasper Burns, who had a stiff leg caused by a mill injury to his knee. But stiff leg and all, Jasper made the long walk twice a day in

ure 9.-Start of road construction on the Crossett Experimental Forest. Road cutting across picture in immediate foreground was the Crossett, Ark.-Bastrop, La. highway.

order to stay alive. Jasper became a valuable permanent member of the Crossett Research staff and worked for the Government until his retirement many years later.

Word that the Crossett Lumber Company was considering selection cutting of their last remaining virgin and advanced second-growth stands, and that the Southern Station had marked the first 2,500 acres for partial cutting spread throughout the country. Visitors by the dozens began visiting Crossett to see the first large-scale marking of timber on a selection basis, and to see development of the proposed Forest Research Center. My diary for May 26, 1934, reads as follows:

"Went to Collingston, Louisiana, to pick up Mr. Demmon (Director of the Southern Station) and Mr. Watzek (one of the owners of the Crossett Lumber Company). Talked over future plans with Mr. Demmon in a.m. In p.m. with Mr. Silcox (Chief of the U.S. Forest Service), Mr. Demmon, Mr. Kircher (Regional Rorester R-8), Mr. Watzek, Mr. Bryant (Prof. of Forest Utilization at Yale University and consultant to the Crossett Lumber Company), Mr. Trieschman (Member of Crossett's Board of Directors), Mr. Sonderegger (State Forester of Louisiana), and Mr. Gillett (State Forester of Arkansas), showing them the East Block selection marking, and the work the Experimental Forest."

Figure 10.–A. G. (Jake) Jacobson, the Crossett Lumber Company's fourth Chief Forester, was responsible for establishment of the district forestry system and for getting the Company through many rough times—when they were attempting to change from virgin timber to second-growth management and harvesting.

And the diary for Wednesday, July 18, 193 reads: "With Wackerman and a Mr. McGow (Julian) of the W. T. Smith Lumber Company Chapman, Alabama) whose company is thinki of practicing sustained yield on their operations

But some of the Crossett officials still were n satisfied that the second-growth pine stands th proposed to log (along with the selectively mark virgin timber) had enough volume per acre permit railroad logging. They, therefore, ask the Forest Service to assist in updating the sta and growth figures for their 146,000 acres second-growth in the so-called NE and N Blocks, located north of Hamburg and south Monticello. They also asked us to propose management and selective logging plan for t area.

Pete Downey, forester for the company, was be in charge of the work. However, before t evaluation was hardly underway, Down resigned and the work was temporarily halte

The company's new forester arrived the fi week of November 1934. He was Albin G. (Jak Jacobson, a University of Michigan Forest School graduate of 1929 (fig. 10). He was i mediately assigned to the company's cutover la study.

Early in 1935, the stand and growth data h been brought up to date. Average pine stand p acre on the 146,000 acres was as follows:

Volume 10" d.b.h. and above - 2,100 bd. Doyle scale

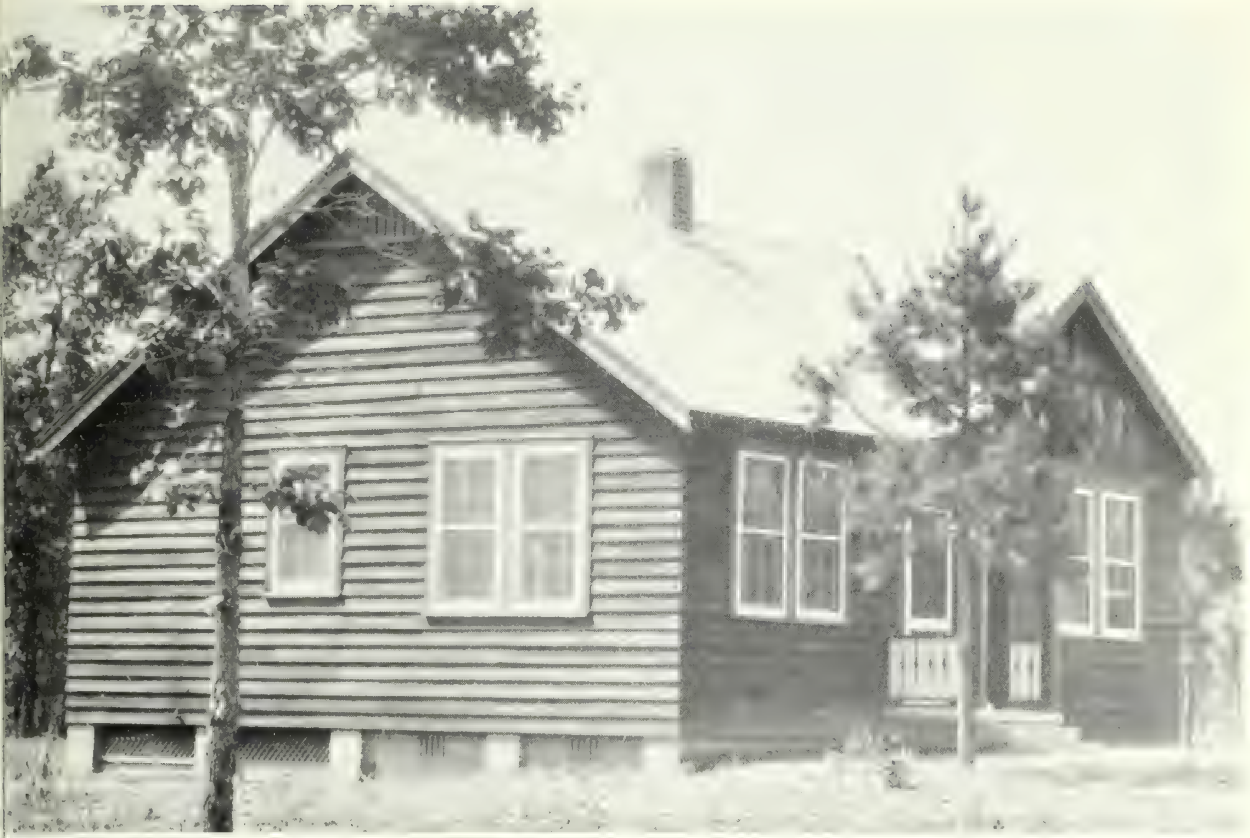
Volume 12" d.b.h. and above - 1,852 bd. Doyle scale

Volume 13" d.b.h. and above - 1,680 bd. Doyle scale

Volume 14" d.b.h. and above - 1,461 bd. Doyle scale

Volume 15" d.b.h. and above - 1,222 bd. Doyle scale

At that time, we determined that at lea 2,500 bd. ft. (Doyle) would be needed to mak railroad logging operation profitable. The size logs that would be needed was unknown at t time, but it was quite obvious that logs produc



igure 11.- Original office building at the Crossett Research Center Headquarters located about 8 miles south of Crossett, Ark., on the Crossett-Bastrop highway. Photo made in summer 1935.

rom trees 10 to 12 inches d.b.h. would be very ostly, especially if produced under a railroad peration.

To put it mildly, the company had doubts bout the future of the sawmill business at rossett. To attempt to make a go of it, they had greed to a proposal to reduce their pine lumber roduction.

MEANWHILE—BACK AT THE FUTURE RESEARCH CENTER

Meanwhile, progress was being made at the uture Research Center, but under considerable ifficulty. Nearly all of the Southern Station staff ere in favor of developing a headquarters area ith office and housing for some of the technical nd supervisory force. Also needed were telephones and electric service, additional road construction, graveling, and other improvements. But extremely little money was available for doing the work. By present day standards, when, with not too much effort, funds can be had for the building and equipping of a laboratory costing a million dollars, it seems amazing that the station could only find funds to build a small office and a small pump house. These were board and batten buildings with rough drop siding on the outside and knotty pine paneling on the inside. The office was built up on blocks with a crawl space underneath. It had a fireplace and a small bathroom. Construction of the office and pumphouse began in August 1934 and was completed in about 3 weeks, at a total cost of $2,400 (fig. 11).

On September 24, 1934, work had begun on buildings to be used as winter quarters by the CCC crew, who was helping on a 100-percent inventory of timber on the Experimental Forest. Location stakes for a house, a filling station, and a four-car garage were set.

For other improvements, we had to scheme and beg and do the work with our own hands (fig. 12). We used the small crew of CCC boys from the Hamburg camp, not only to make the 100-percent inventory of trees on the new Experimental Forest, but to help survey the forty and compartment lines on the forest. They also helped drill a water well at the headquarters area, and cut brush from the fire lines that were to be constructed at quarter-mile intervals throughout the forest.

By the end of 1934, much of the 13 miles of pick-and-shovel-built F.E.R.A. (Federal Emergency Relief Administration) roads were completed, and some of them had received a thin layer of gravel that we had loaded and unloaded by hand from a gravel pit 5 miles away.

The F.E.R.A. came to an end, but it was succeeded by the W.P.A. (Works Progress Administration). We obtained a project and a small allotment of funds for work on the Experimental Forest on July 29, 1935. The W.P.A. administration allowed us to "hire" some men with carpentry, log construction, and other skills, along with the allotment of those with only common laborer experience. The W.P.A. administration also provided us with a small amount of money to purchase needed lumber, nails, and other materials.

Since long pine poles of 10 to 12 inches butt diameter and with a little taper could be had for $1.00 and less per pole (if we did the cutting, peeling, and hauling) we decided to construct a custodian cabin and bathhouse, a superintendent's house,a forester's residence, a four-car garage, and a filling station, out of logs. Rafters were made out of small, round pine poles. Roofs were covered with cypress shakes produced by our crew from old, generally hollow, cypress trees given to us by the Crossett Lumber Company. Pieces of 2 x 4's and 2 x 6's were set against the logs on the inside of the rooms and pieces of knotty pine paneling were nailed to these. Dried, dressed #3 (knotty) boards were obtained for $17.50 per M bd. ft. If such boards were selected for sound knots, the price was $22.50 per M bd. ft. And if each side of the board was bevelled so as to produce a "V" joint when construction was completed, the cost was $27.50 per M bd. ft. (fig. 13).

In those days power tools were not available, so all cutting of the trees and logs for the buildings had to be accomplished by the use of two-man crosscut saws and axes. Fitting of the logs at the corners of the buildings had to be done by trial and error by the use of axes and large chisels. Concrete for supporting walls and cellars had to be mixed by hand in 4 x 8 feet troughs, with gravel and sand loaded, hauled, and screened by our crews from local pits.

Construction of the various log buildings started on September 30, 1935, and was largely completed by the middle of the summer of 1936. To give one an idea about "building without money," by far the most expensive of the construction jobs was the forester's residence (fig.14). This was a 50 x 58 feet (inside measurement) H-shaped house with a basement, hot-water heating system, and fine hardwood floors in most rooms. Total cost of all logs for the house was $10 (standing tree value), and total cost of the house was less than $7,000, including labor. Except for a small amount of architectural and supervisory help, the total cost of all these original log buildings to the Southern Station was only a few hundred dollars.

As this construction work was getting underway in summer 1935, the director of the Southern Station, the division chiefs, and some of the research personnel had a final meeting to agree on the assignment of research study areas on the Experimental Forest. The result was that 80 acres was to be left untouched as a "Natural Area"; 30 acres was for a native tree Arboretum (fig. 15); 80 acres was for farm forestry studies; 280 acres was to be set aside for small plot, "test tube", or fundamental studies; 880 acres was for large compartment studies; and 330 acres was for administrative use and for later assignment.

MORE GROWING PAINS

The winter of 1934-35 was not unusually cold, but we learned that, though fireplaces are nice to look at, they are not exactly the way to heat an office. Especially if much inside work is to be done. So we talked someone into providing enough money for a small, wood- and coal-burning, circulating, gravity-flow, hot-water furnace. The only thing wrong with that was that we needed a cellar for it. But that didn't stop us.

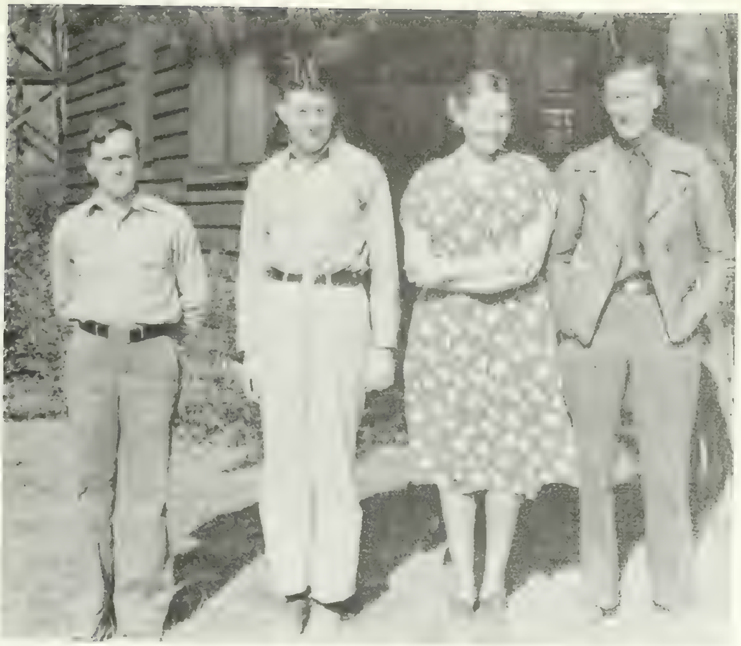


Figure 12.–First staff of Crossett Experimental Forest in March 1938. Left to right they are A. G. Williams, Edwin Hughes, Lucille Futhey, and Russ Reynolds.

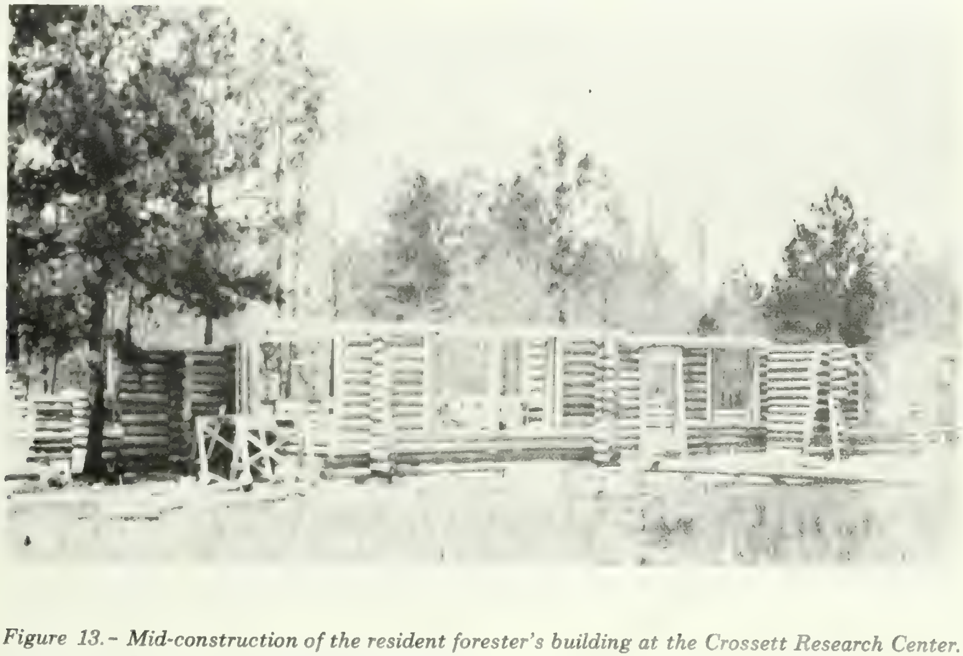


Figure 13.– Mid-construction of the resident forester's building at the Crossett Research Center. Is it likely to ever make a house?

Some of us began acting like moles, and with short-handled shovels we crawled under the office and started digging a cellar without disturbing the footings of the building. In short order we had our forms in and concrete mixed and poured. We bought used pipe and radiators and, before the end of January, we had lots of wonderful heat.

We had no money for coal to fire the furnace, but we did have an unlimited supply of good hardwood for the cutting. So, we used wood. Unfortunately, though, the fire had to be stoked at midnight and at about 4 a.m. if we were to have a warm building when it was time for the office staff to go to work in the morning. As the boss, I would not dare ask someone else to do the nighttime stoking of the furnace, so I did it at the same time that I fed the furnace in the big house. But in those days one had to do many "extra" jobs in order to keep the project going.

There was no problem getting all the female W.P.A. help we needed for work on the mass of time-study and yield data collected on the Pack Selective Logging Study—if we had some tables, chairs, and desks. We learned that the Veterans Hospital at Alexandria had some used office furniture that they were willing to give us. To this we added two large tables that we built from glued sections of 1 inch x 1½ inches x 8 feet red oak white oak, and post oak. These were massive an heavy tables but beautiful when sanded smoothed, and finished with natural varnish They were still around in 1970.

THE BEGINNING OF PARTIAL CUTTING ON CROSSETT LANDS

The cutting of selectively marked virgi timber in the Crossett Company's East Bloc began in 1935. It was done under the sam railroad logging system as was used when th virgin timber was clearcut. However, with th reduced harvest per acre the costs increased. B mid-1935 the company had also started som railroad logging of its second-growth in selecte stands. Here, too, the low volumes of log available per acre and the small size of logs cause production costs to skyrocket.

The company had begun making contract with a few log contractors for the cutting o marked timber for delivery by trucks to th company's East Block main line railroad and t landings on the A.D.&N. Railroad at Monticello Lacy, Fountain Hill, and Pugh, Arkansas.

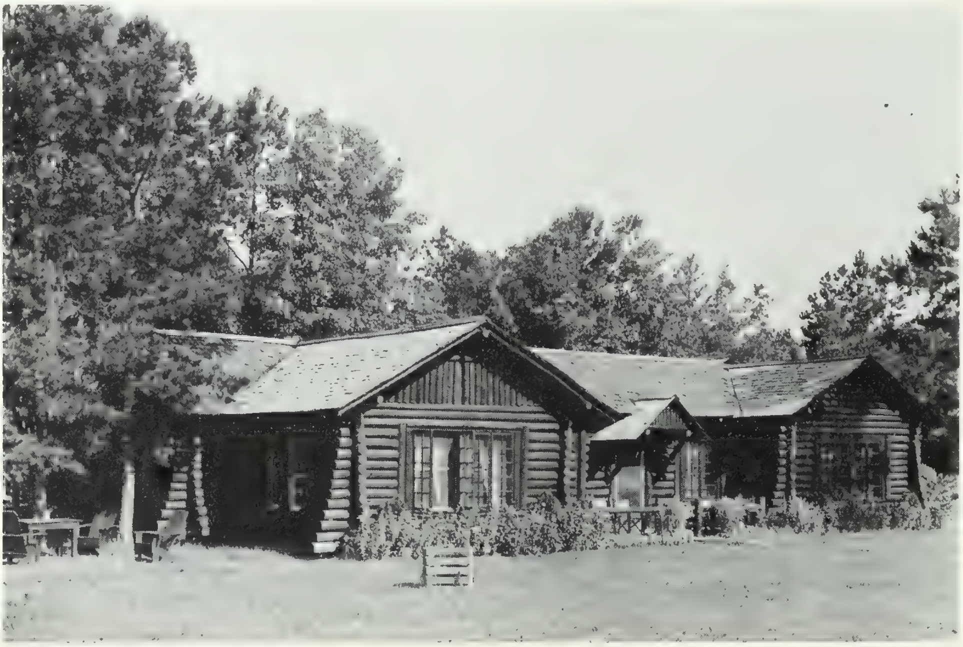


Figure 14.- The completed house in 1937. It had a 18 ft. x 25 ft. living room, a 16 ft. x 18 ft. dining room, a large kitchen, two bedrooms and a sleeping porch, a bath, a laundry room, and a cellar. (FS 350851).

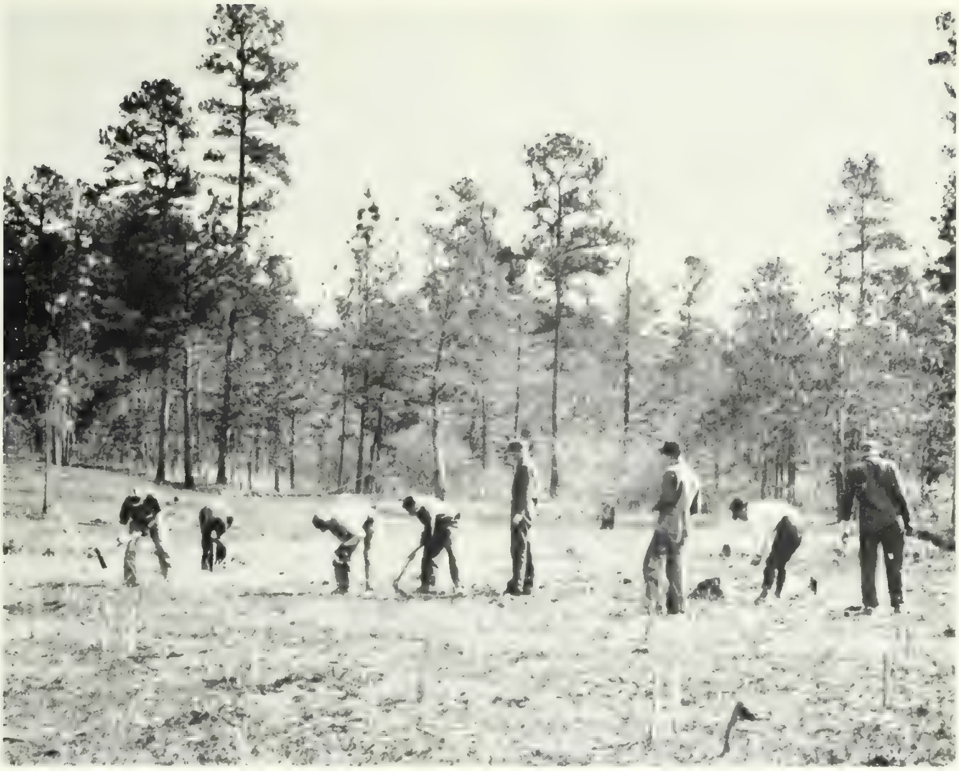


Figure 15.-Planting tree arboretum on the Crossett Experimental Forest during the spring of 1935. Timber stand in the background is typical of the unmanaged second-growth stands that were present on the forest when research began in 1935.

THE FIRST USE OF TRACTORS FOR SKIDDING

Until this time, all skidding of logs at Crossett nd in the region was accomplished with the use of orses, mules, and oxen. Between late spring and te fall it was usually possible for trucks to drive irectly to the logs in the woods, so the teams nly had to bunch one or more loads in a spot. In et weather, however, trucks had to stay on the ery few hard surface roads, and skidding had to e to these roads. With railroad logging where ere were logs of up to 500 bd. ft. each, skidding n average one-eighth of a mile was a real roblem, any time of the year, even though two-heel "bummers" were used to carry the front end f the logs. During long periods of wet winter eather it was almost an impossibility. Tractors r use in skidding logs in the woods were unheard f.

At this time the Caterpillar Tractor Company ad crawler tractors that were sold for use around uilding projects. Since the log skidding problem was a universal one, it was thought that tractors of this type might be used for winter logging and, in fact, anywhere that skidding distances were long at any time of year. Consequently, after several conferences and planning sessions, we decided to undertake a tractor skidding study in the East Block area, where logs would be skidded to a railroad landing. It was a time and cost study to determine the number and volume of logs of the different sizes that the tractors could carry per trip. We also computed the cost per M bd. ft. for different distances of up to a half-mile. The study got underway in the spring of 1936 with Robert Worthington of the Southern Forest Experiment Station in charge. He used a crew of CCC boys to collect the necessary time and volume data.

The first of April was the date chosen for the start of the study since this is the time of the year when soil conditions are less firm and skidding of logs the most difficult. However, April 1936 happened to be one of these rare spring months when ground conditions were good and there was very little rain. Nevertheless, the study was undertaken as planned.

Relatively small RD-4 tractors were the first ones tested. It soon became apparent that, under dry conditions and for short distances, teams of horses or mules could skid logs at a cheaper rate than the tractors. It was also true that, for distances greater than about 400 feet, tractor skidding cost per M bd. ft. increased sharply with distance. This seemed to be true largely because the small tractors could not carry enough volume of standard length (12-20 foot) logs.

In an attempt to solve this problem it was decided to produce long logs (24 feet to tree length) with the stems bucked to regular length at the concentration point (or landing) next to the Company railroad. This reduced costs somewhat but not nearly enough.

Next, it seemed that larger tractors might be desirable and cheaper, per M bd. ft., because of their greater power. So two tractors, an RD-6 and an RD-7, were shipped in for study. They could and did pull a much larger load of tree length logs, especially when skidding pans or arches were used to carry the front end of the logs off the ground.

Another important finding was that the skidding cost varied with the size of the average tree or log, partly because of the volume of the average load that could be carried and partly because of the extra time required to assemble load of small logs.

Finally, we found that under no set of cor ditions could the tractors tested skid logs distance of one half mile or more at an acceptabl cost.

Later studies under winter or wet weathe conditions, when soil moisture was high, ir dicated that tractors could be depended upon t move logs from stump to loading point when tear skidding was impossible. Also, tractors could b stuck and almost buried on certain soils, requirin much loss of production while they were being du out. Nevertheless, tractors were in the woods t stay.

A FULL-BLOWN CRISIS DEVELOPS

While all these projects and studies wer underway, a full-blown crisis developed at th Crossett Lumber Company. The Company wa still operating in the "red" at the end of 1935, an Company directors told Mr. Arnold (the genera manager) that, unless he could get the Compan

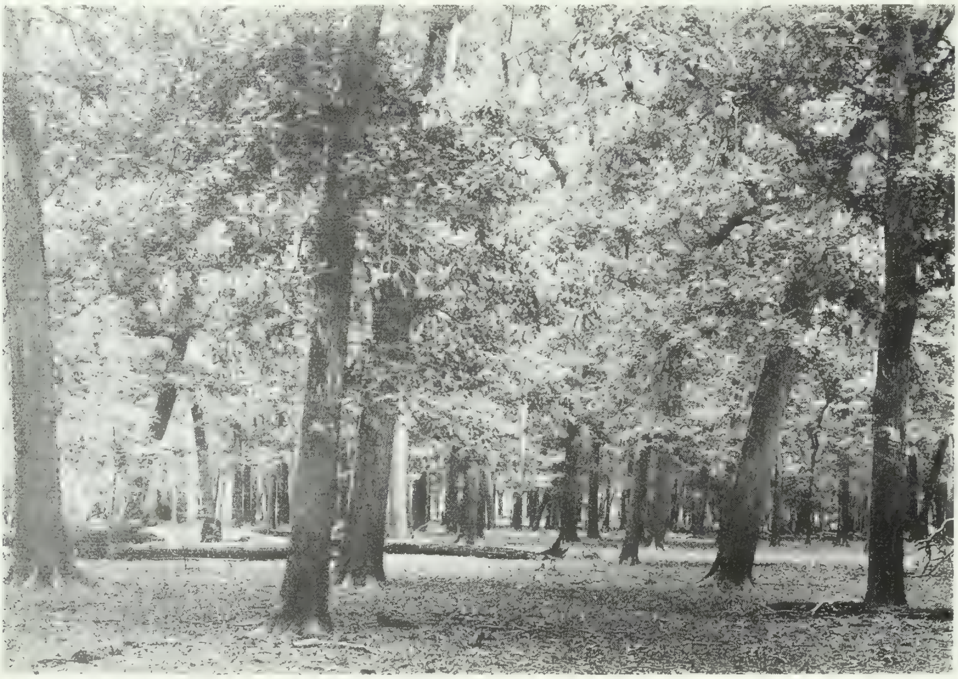


Figure 16.- Ouachita River bottomland in July 1937. This is a typical virgin hardwood stand of Tensas Delta country of Arkansas and Louisiana, overmature and defective. (FS350894).

perating profitably before the year was out, the irectors would have to change managers—and erhaps some other personnel.

Mr. Arnold in turn called in Albin Jacobson nd said, "you damn foresters got us into this ess, now you had better get us out." Jacobson ad a good idea as to what the trouble might be, ut he asked the Director of the Southern Station r help in solving the problems. The Director rdered "all steam ahead." Because it was a ardwood log utilization problem as well as a pine g problem, the Director asked John Putnam, ardwood expert for the Station, and myself to ssist Jacobson.

First, the hardwood utilization problem was ckled. The company had some years earlier, urchased a considerable acreage of virgin uachita River bottom hardwood land located in e flood plain adjacent to and east of the river ig. 16). The site was quite poor. Most of the olume was overcup oak, and the trees, although good size, contained only about 1½ logs per tree. ineral stain was quite common in the wood. The mpany had overestimated the volume and uality present on the area, and was attempting make up for this by cutting and sawmilling any logs of doubtful value.

Based on Putnam's knowledge of quality ields of lumber to be had from logs of various zes and grades, and on observation of grade ields in the mill, a considerable volume of uachita River bottom logs that were banked ong the company's logging railroad were assified into three grades. Class 1 logs were ose that obviously would be profitable to log nd mill. Class 3 logs were those that obviously ere unprofitable because of rot, large knots, nall size, and other reasons. Class 2 logs were ose that were questionable as to profitability.

Many logs from each class were sawmilled, nd we recorded the lumber volume and grade. e also recorded the sawmill time per M bd. ft. of mber yield. We determined logging and milling sts for logs of each class and subtracted this nount from the green chain value of the lumber. he end product was a figure representing net turn per M bd. ft.

From the above study, we determined that the mpany was making a good profit on the Class 1 gs. It was breaking even or making a small rofit on most of the Class 2 logs, but it was sing so much money on the Class 3 logs that the hole operation was unprofitable.

The problem was solved by the establishment of hardwood utilization standards for log production. Logs of various species, or species groups, had to have a certain size and log grade before they would be cut and brought out of the woods. The hardwood logging and milling was apparently never a very profitable operation, but this study and follow-up put it into the black.

After a short review of the pine operation, it appeared that the red ink in the financial statement was, like the hardwood problem, largely the result of too many unprofitable logs being brought into the sawmill. To try and produce the large volume of logs necessary to keep the two large mills running, the woods division was scratching for all the logs they could get. In marking of the East Block virgin timber, trees with heartrot and others that were very limby and low grade, along with many very high-grade trees, were spotted and later cut for logs. Many of the trees with heartrot yielded large logs but generally with only a thin layer of solid wood toward the outside. The rest of the cross section had rot in various stages, and from this only unprofitable Grade 4 lumber could be produced. Many logs from the tops of high quality trees and from the whole stems of very limby trees produced logs with very large knots, and often boards with loose knots.

In cutting the marked and unmarked second-growth stands, many small logs were produced, as well as many logs with large knots. The Pack Selective Logging Study—and the follow-up mill-scale-study—produced yield, cost, and lumber value data for the various sizes and grades of such logs. A summary of this data gave all the information needed to indicate what kind of logs would be profitable and what kind unprofitable for sawmilling at Crossett.

Little data, however, were available on lumber out-turn from the large rotten-core logs from the virgin stands. We ran a mill-scale study of a representative sample of such logs to determine the amount of defect that the logs could have before becoming unprofitable. A similar test was also run on top and rough logs to determine characteristics of the unprofitable ones.

From these studies, utilization instructions were prepared to help those who were responsible for log production keep most unprofitable logs out of the sawmill.

The application of such standards meant that many of the smaller and the rougher logs from

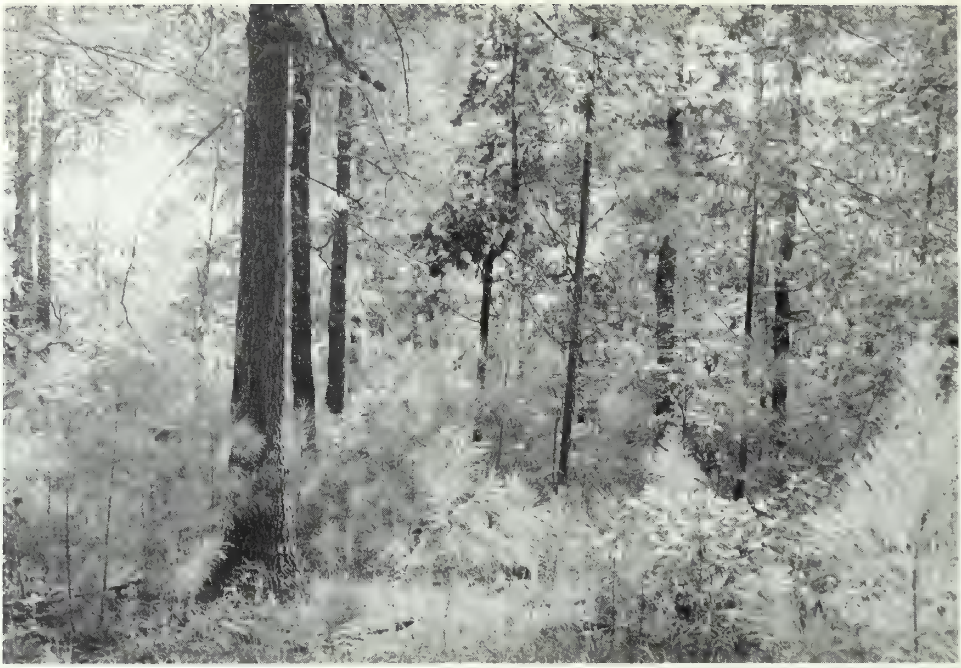


Figure 17.- Low quality hardwoods, most of which had been left at the time that the virgin timber was cut 15 years earlier, had taken over this pine site on the Crossett Experimental Forest by 1935. (FS 350923).

small trees could no longer be used in the relatively slow, and relatively expensive, mills that had been designed for operation on large virgin logs. Much of the upper stem of the larger second-growth trees also had to be left in the woods.

FIRST RESEARCH ON THE CROSSETT EXPERIMENTAL FOREST

As has been indicated earlier, the second-growth pine-hardwood stands present on the new Experimental Forest contained many hickory and red, water, post, and white oak. Some of the post oak and a few of the other species were as large as 24 inches in diameter. Because of past fires, many large trees contained rotten centers, but a few were of the right grade and size to make merchantable logs. The hardwoods generally occurred singly, or two and three together, and interspaced among the pine. In many places, however, there would be an almost solid stand of hardwood, up to an acre in size, with pine reproduction, seedlings, and saplings underneath (fig. 17).

If we were to intensify management of the stands and increase yields and returns, we somehow would have to reduce greatly the hardwood component of the forest. The use of hardwood for pulpwood in those days was unheard of Many people burned hardwood for heating an cooking, but there was little market for the wood If a person needed some wood he could have a unlimited amount from company land just for th cutting.

Fortunately, Crossett had a so-calle "charcoal plant" that had been built to use cutoff and trimmings from their hardwood sawmill Because of trouble with uniform carbonization o this material, they had started using small roun and split sections from the trees in the woods. Th sections were 52 inches long, and could not b over 5 inches across on any face. In those days i was said jokingly that the company "would tak any hardwood species—as long as it was oak an as long as the piece contained few, if any, knots.' But the cutting of "chemicalwood" provided market for some of the unwanted hardwoods (fig 18).

Because of this, our first "study" undertake on the Experimental Forest dealt with improvement cutting. The Crossett Lumbe Company had agreed to take all of the chemicalwood we wished to produce, so we decided t determine how much of the product the previousl unmanaged stands would yield per acre, ho much it would cost to produce the product, and how many trees unsuitable for chemicalwood we would have to girdle. We acquired a couple of used 1½-ton trucks and built chemicalwood racks on the back of each. We then picked several men out of our E.R.A. crew with woods experience, and went to work on the several compartments that had been marked previously for the study. In those days the market price for chemicalwood was $2.25 per "unit" (52 inches wide x 4 feet high x 8 feet long) of wood delivered to the chemicalwood yard in Crossett. We did not make a lot of money, but we put a lot of hungry men to work and we greatly improved the growing conditions and pine stocking on the areas treated. Later we applied the practice to nearly all the Experimental Forest that was to be used for compartment studies.

DEVELOPMENT OF A MARKET FOR PULPWOOD

Two kraft paper mills had been built at Bastrop, Louisiana, in the 1920's, and both used pine for raw material. However, their requirements were relatively small and could easily be met locally. The Crossett area had no market for its pine or its hardwood from trees that needed to be removed in thinnings, or from tops of trees that had been cut for logs.

It is not known when Crossett Company officials started thinking about the possibility of building a pulpmill in order to use this material. But it was possibly by 1933 when the company's forestry program started to take shape. By June 7, 1935, the discussions had gotten to the point that they engaged Spain and Company, Consultation Foresters, of Memphis, Tennessee, to make a check cruise of their pine timberlands to determine how much material might be available to a mill.

By February 1936, a secured loan from the Reconstruction Finance Corporation had been approved, largely because it would provide employment for many unemployed men in the area. Construction plans had been nearly completed for a 150-ton kraft mill, and the location for the mill had been chosen (fig. 19).

Things were stepping right along. My diary for Sunday, February 16, 1936, reports, "Spent the day with Director Demmon inspecting the Experimental Forest and the Experimental Forest buildings that were under construction. Inspected the Improvement Cutting study on the forest and looked over suggested pine pulpwood thinning study areas. Also looked over some of the Company's selective logging and the site for the new pulpmill."

In the western part of the shortleaf-loblolly-upland hardwood type, in Arkansas, Louisiana, Mississippi, and Texas, about 5 to 10 percent of the forest area was made up of dense, even-aged loblolly or loblolly-shortleaf pine stands. A few of such stands resulted from a severe fire or windstorm.

However, by far the most were "oldfield"

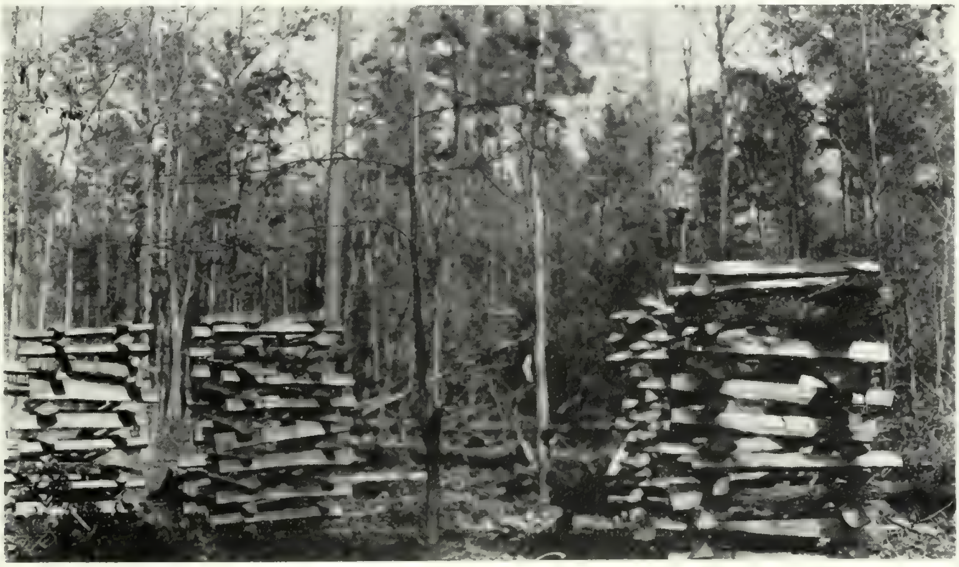


Figure 18.- Hardwood "chemicalwood" stacked in the woods for drying.

stands. In the early years of farming, the owners of the farms would clear a patch of 5 to 20 acres of trees and brush, and plant the cleared patch to corn or cotton or other crops. Commercial fertilizers were unheard of, and the natural fertility of the fields would be reduced from year to year. After so long a time, the owner would clear up another field or two and abandon the worn-out fields. Generally pine seed from the surrounding forest would be blown into the abandoned patches, and a dense stand of young pine would result.

Until 1935 or thereabouts, there was much question as to whether these oldfield stands were a blessing or a hindrance. In most localities there was no such thing as a market for pulpwood. And there was only a very limited market for treated pine fence posts. If the owner wished to use such areas for grazing, he had the task of clearing the abandoned fields of the pine saplings and the new stems that continued to come in from natural seeding. If the owner of such thick patches of oldfield pine did nothing to them and the stands escaped a serious fire, as many trees as could survive the severe competition (among one another) would eventually reach pulpwood size. And finally many would reach small sawlog size.

But such stands still had little or no value. Until about 1938, an individual (if he had the money and a strong enough belief in the future) could have purchased hundreds of thousands of acres of such stands, with the equivalent of up to 35 cords of pulpwood per acre, for $5-$6 per acre. At one time I purchased 640 acres of such stands with loblolly pine of pulpwood size as thick as "hair on a dog" for $6 per acre. This included cost of land, the trees, and all mineral rights.

When many of the trees in such oldfield stands approached sawlog size, it was customary for the nearest sawmill owner to purchase such stands under a 20- to 30-year "timber deed." This meant that the purchaser would make an estimate of the volume of log-size material on the property and then get the owner to give the company 20 or more years in which to cut the stand. The price per M bd. ft. was often not more than $2.50. Because the estimated volume was based on Doyle scale and the sawtimber trees were small, the volume paid for amounted to very little. The purchasers of such stands would usually wait until the last year of the timber deed before cutting the stand. The result was that the purchaser would usually cut 2 to 10 times the volume and value that was paid for in the earlier years. Too, over the 20- to 30-year period, the owner of the land would pay the yearly taxes on the property—and he was expected to also keep fire and trespassers out of the timber stands.

GROWTH AND YIELD TABLES—CONCEPTS

The dense oldfield stands did have a useful place in the scheme of things. Shortly after the Southern Forest Experiment Station came into being in 1921, researchers had begun collecting data for the construction of growth and yield tables for fully stocked stands of the four principal species of southern pine—loblolly, longleaf, shortleaf, and slash. At the time, and even into the middle 1930's, "fully stocked" meant all the trees that one could have growing on a given area, on a given site, at a given time. For instance, it was assumed that a fully stocked stand of loblolly pine growing on an 85-foot site should have about 140 square feet of basal area at 30 years of age, because stands could be found with this amount of stocking. This concept was undoubtedly imported from Europe at the same time that the first European foresters came to the United States. In any event, work at the Southern Station resulted in a quite famous U.S. Department of Agriculture-Forest Service publication. It was known as Miscellaneous Publication No. 50. It presented the first comprehensive growth and yield figures for fully stocked stands of the four major southern pines. Such information was based on stand age and tree height or log length.

Stands of these pines that had basal areas less than that shown in the tables were considered understocked. Furthermore, in those days most foresters thought that the growing stock in "understocked" stands should be built up to this full volume in order to obtain maximum growth. This was held to be true for board-foot as well as for cubic-foot values.

Another interesting concept that held sway until the mid-1930's was that board-foot growth and cubic-foot growth per acre per year was directly related to percent of full stocking. If the stocking of a given stand was 50 percent of the full stocking, as shown in the growth and yield tables, the cubic- or board-foot volume growth would be 50 percent of the values for fully stocked stands.

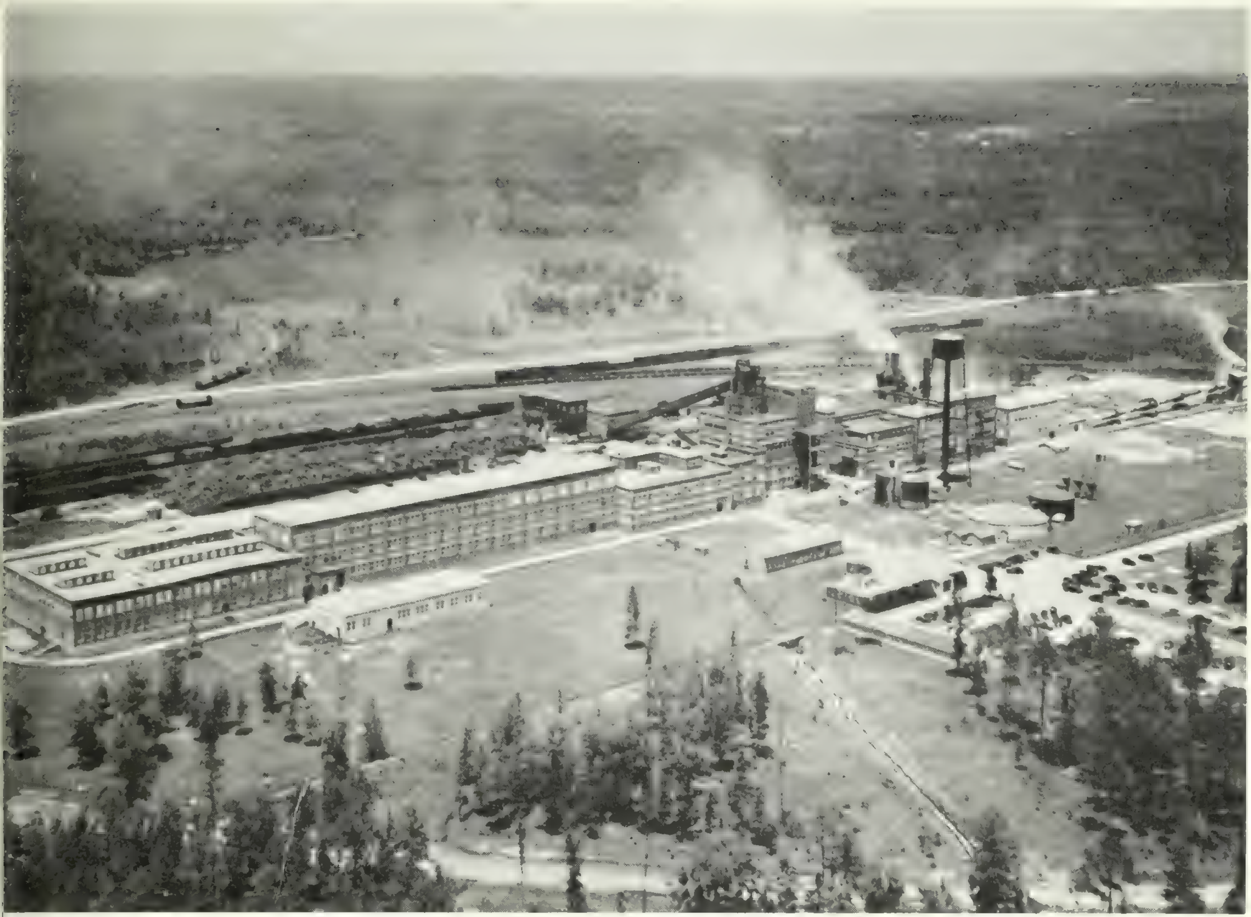


Figure 19.– The Crossett pulp and paper mills—built in 1937 to utilize small trees removed in thinning and tops of sawlog trees.

JIM GIRARD

A few of us foresters did not agree with such a concept but it was James W. (Jim) Girard, a nonforester and nonresearcher, who proved that the idea was erroneous. Jim, who had been a timber cruiser and logging engineer in the western forests, had been hired by the U.S. Forest Service to help the Assistant Director of the National Forest Survey. Almost immediately, Jim clashed with the Director and other high-level Washington personnel in charge of the Survey. They had intended to publish data on the stocking and growth of an area of Florida's timberland (as I remember it) that had been inventoried by the Survey staff. Stocking per acre was only about 30 percent of that shown in the Miscellaneous Publication #50 growth and yield tables, so the point was to be made in the survey report that the growth was only 30 percent of normal.

Jim would not accept such a statement. He was positive that the growth would be greater than this. After many conferences and harsh words on the subject, Jim proposed a study of pine growth in relation to stocking. This was finally agreed to and was conducted in ponderosa pine stands of various stocking in Montana in about 1935.

Results of the study conclusively proved that Jim was right and that it was possible to have, say, 60 percent of maximum growth in stands with only 40 percent of full stocking as shown by the growth and yield tables. This finding was later proved correct at the Crossett Research Center and elsewhere, and led to the use of increment-core and permanent sample-plot studies to determine actual growth in understocked stands. It was also the reason that 100-percent repeat inventories were insisted upon in later compartment and small-plot studies undertaken at the Crossett Research Center.

This same Jim Girard was the idea man for the form-class volume tables he later developed in collaboration with Clement Mesavage, who at the time was on the staff of the Southern Forest Experiment Station. The first such publication had the title, "Tables for Estimating Board-Foot Volumes of Timber." For some unknown reason the publication was not given a number and was marked "For Administrative Use." It was never published for general use. The Southern Forest Experiment Station in 1947 did publish "Tables for Estimating Cubic-Foot Volume of Timber" by Clement Mesavage, which was based on the Girard form-class idea. Both Girard and Mesavage were disappointed that the Forest Service didn't publicly accept the Girard form-class tables and recommend them for general use.

THE PULPWOOD THINNING STUDY

Because of the initiation of a market for pulpwood, and because of the very slow diameter growth of trees on most of the heavily stocked oldfield (and some natural forest) stands, it seemed desirable to determine the effect of thinning in stands of this type. Thus, after much thought and planning, the second study to be undertaken at the Center was one on pulpwood thinning. It was begun on June 11, 1936. The objective was to determine the present and future yields, returns, and cost when: (1) about 200 of the best trees were reserved per acre on a spacing of 15 x 15 feet; (2) about 100 of the best trees were reserved on a spacing of 21 x 21 feet; (3) 70 of the best trees were reserved on a spacing of 25 x 25 feet; (4) 40 of the best trees were reserved on a spacing of 33 x 33 feet. In each case, trees smaller than 6 inches d.b.h. were not counted as crop trees and were allowed to remain on the plots.

At the time, to counter severe criticism of clear-cutting, the Southern Pulpwood Association had a cutting "rule" that it urged its members to use. The association further urged its members to purchase pulpwood only from dealers, contractors, and timberland owners who cut in a manner that would equal, or be better than, the standard adopted. The minimum standard for pine pulpwood was to "leave all trees up to and including 7.5 inches d.b.h. and leave one 9.5-inch or larger tree every 50 feet." Such a treatment was included in the study. Also, uncut check plots were included, making six treatments in all. The study was undertaken in a 44-year-old oldfield stand with an average basal area of about 140 square feet per acre.

We found that the most net-cubic-foot growth for the first 10 years was on the plots thinned back to 200 trees per acre. The most board-foot growth was about the same on plots thinned back to 200 and 100 trees per acre, with the plots thinned back to 70 trees per acre not far behind. The uncut check plots were far behind in both net cubic and board foot growth.

Figure 20.-The famous Rose Inn at Crossett, Ark., 1934.

SMALL-TOWN LIVING

Up until July 9, 1936, I and Geneva, my wife, lived in Crossett—first at the Rose Inn and then in a house on the southwest corner of the intersection of what is now Cedar Street and Third Avenue. The house was set aside for rental to Southern Station personnel.

The Rose Inn was a large three-story wooden structure with open walk-up stairways (fig. 20). It was Company owned and provided the only public overnight housing in town. It had a large lobby with a big fireplace and a long row of rocking chairs. Another long row of such chairs adorned the long, covered front porch. Rooms on the third floor were reserved for unmarried school teachers, who were required to live there. Not too much space was required since there was only one white and one black school in town. Crossett was very much off the main roads. In those days the rooms on the second floor usually could take care of visiting lumber company officials, plus two or three of the single men who worked for the company and did not have other housing. It also accommodated an occasional salesman and other visitors.

The large Rose Inn dining room, always with sparkling white tablecloths on the tables and waiters with white jackets, was famous for its good food. For many years, men had to wear ties and coats before they were admitted to the room. To be reasonably sure that those who came without proper attire could have something to eat, Mr. Boardman, the hotel manager, kept a supply of extra coats and ties on a clothes tree just outside the room.

Geneva and I were allowed to live and eat at the hotel on a monthly rate that was similar to the one paid by the other regulars—$30 each per month. This included steak every night, if one wanted it, and always plenty of hot biscuits and many choices of potatoes and vegetables.

Crossett was strictly a lumber company town with all of the houses built, maintained, and owned by the Company (fig. 21). The houses were all built up off the ground on brick or concrete piers with plenty of crawl space underneath for the installation of piping and for reducing the problem of termites (fig. 22). No insulation of any kind was used, so the houses were very drafty and cold in winter. All buildings were painted the same color and many looked alike so one learned to know his house by some distinguishing feature in the yard. No yard was complete without a servant's quarters in back, and most homes "enjoyed" outside toilets.

Because of the low wages paid (by sawmills in general, including Crossett), most families kept cows and chickens to help make ends meet. There was no such thing as a stock law in those days. So, after milking time in the morning, the cows were turned out of each back yard to hunt for grass and other vegetation to eat during the day. Several people owned horses and pigs, and there were even a few mules. These, along with the cows, roamed at will up and down the streets

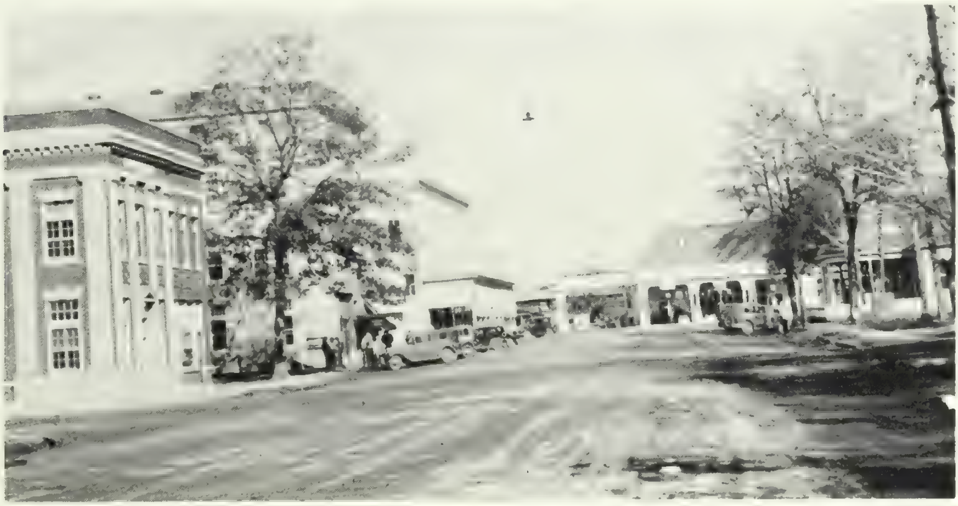


Figure 21.- Main street of Crossett, Ark., 1934.

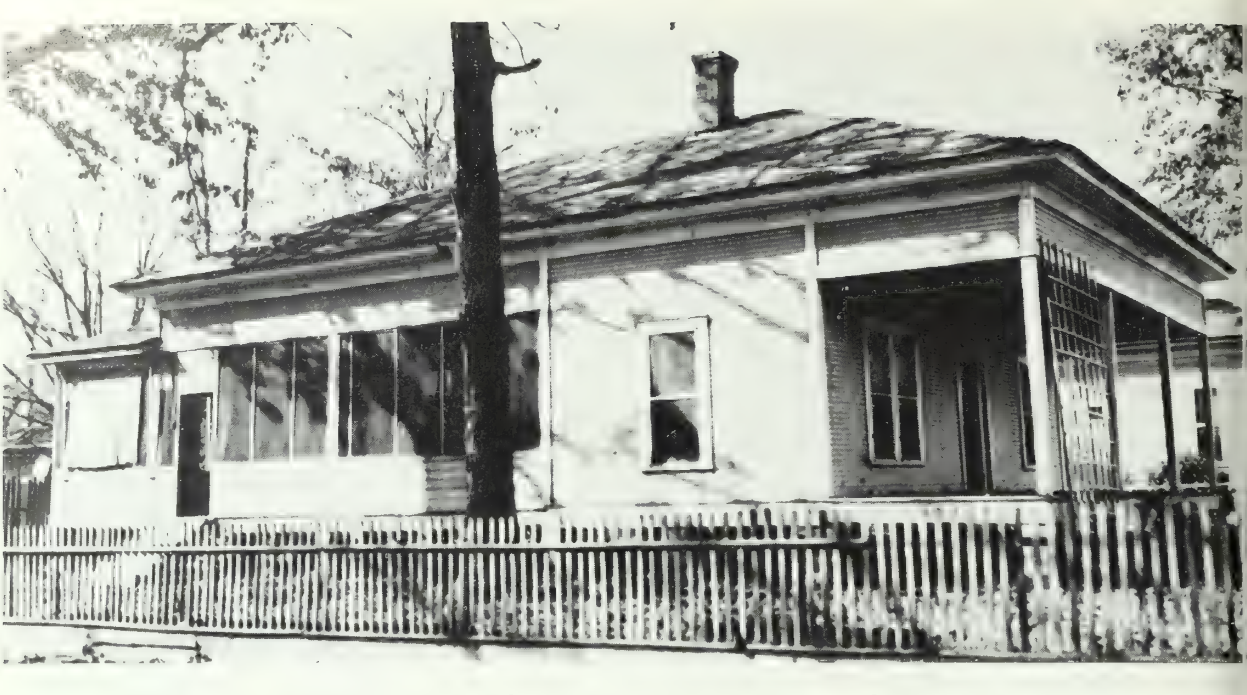


Figure 22.- The Reynolds residence in Crossett from 1934 to 1936, a typical Crossett house at the time.

including the area that might be considered "downtown." Most streets in town were unpaved, although some had a weak covering of gravel and blacktop. In wet weather, one had to try to dodge not only mud puddles but also cowpiles and other "offcasts." In dry weather, it was just the latter.

Because of the roaming livestock, all yards were enclosed by a wooden picket fence. Wooden picket gates had a large barndoor, butterfly hinge mounted horizontally at the top to keep it closed. To open the gate, one would flip one half of the hinge back on the other half. The grass in the yards always seemed to be greener than that outside the fence—to the livestock at least—and many people had some tasty garden vegetables. Thus, as one could expect, if a given gate was not locked by the hinge, or if someone left it open, the householder would more than likely have a yard full of livestock in no time. Occasionally even the hinge "lock" on the gates was not enough to protect the yards from grazing animals. There was one old cow, with only one short crooked horn, that was smarter than 99 percent of all animals in the country. She learned that if she would turn her head sideways she could push her short, little crooked horn under the hinge and flip it over. Then she could pull the gate toward her and thus open it—and walk in. After watching her pull her trick a few times—especially after losing some of our garden to her—we, and many of our neighbors, installed more foolproof locks on the gates.

One night Geneva and I were awakened in the middle of the night by a constant tinkling of a bell. After trying to go back to sleep without success, we realized that somehow we would have to get rid of the noisemaker. Geneva had purchased a sack of potatoes, of good size, the day before so I appropriated three and went out the side door toward the noise. As I did, I suddenly realized that we were in the midst of a pea-soup fog that was so dense one could not make out a shape more than 10 feet away. I carefully headed down the back door steps and toward the tinkling bell. When I reached the yard fence, I let fly with a potato toward what seemed to be the middle o the animal. The potato found its mark and hit with considerable "plop." The slow "ding-ding" immediately turned into a rapid "ding-ding-ding" and two or three horses or mules took off up the street. About this time from across the narrow street in the next yard came "tee-hee-hee" and then "haw-haw-haw." It was the voice of Mr Arnold, manager of the Crossett Lumber Company. He and Mrs. Arnold had been awakened by the same bell and he was also out in his yard trying to decide what to do about the bell. After a good laugh together, we both went back to bed and let someone up the street worry about what to do about the bell. To this day I have wondered what would have happened if I had missed the mule with the potato and hit Mr. Arnold!

What sidewalks there were in town were wooden, and although these were kept in pretty good repair one always had to watch for a broken or rotten board when walking thereon.

There was only one store in town and this was—you guessed it—the "company store." It was located on the corner of what is now Highway 82 and Main Street. It was a large rambling wooden building with a second-story mezzanine all around the large main floor. The store had many departments, including groceries, hardware, clothing, and furniture. If one wanted drugs or ice cream, such items could be had by descending two steps into an attached separate room.

All sawmill and woods employees were encouraged to trade at the company "sto." And to help bring this about the workers could draw one week's pay in advance, but this was in the form of coupon books that were good only at this store. The Company owned all the land in town and an area of about 2 square miles surrounding. And, except for the railroad buildings and Western Union, no other private enterprise was allowed. Those who wished to establish a business had to purchase land outside the village limits. It was because of this that North Crossett, West Crossett, and South Crossett came into being. Prices in the stores in these places often were a bit cheaper than in the company store, and those who could resist the temptation of "borrowing" against next week's pay could have cash to trade in the outlying communities.

Because the company owned all houses and other buildings, and would only rent, it could readily determine who would occupy each house. They would rent only to those who worked at the mills or offices, plus the few exceptions like Geneva and me who worked for the Forest Service. Thus, there was no unemployment in town. And very little crime and drinking. If an employee did not produce at his job or caused any trouble, out of town he would go.

Although pay in the sawmill and woods was not large, the cost of rental living quarters was very reasonable. Rates ranged from $5 to $17 per month for most houses. And one could buy a refrigerator or stove on "time" at the company store at a very low rate per month. One could also obtain all the wood he wanted for heating and cooking just for the cutting on company lands.

RESEARCH STUDIES MULTIPLY

Although Geneva and I enjoyed our Crossett living, July 9, 1936, was a big day in our lives. By this date, construction of the big log "Forester's Home" at the Branch Station headquarters, located 7 miles south of town, was far enough along for us to move in (fig. 14). And move in we did, with joy. This was to be our home for the next 33 years, in spite of many attempts to move us back to New Orleans, or to other locations, so that we would have more contact with other scientists and "would not go to seed," as some of the Washington Office staff called it.

Meanwhile, the building program was winding down. Office work on compilation of data from the Pack Selective Cutting Study was expanding, both in Crossett and in New Orleans. Based on data from the Pack study, local cubic-foot and board-foot volume tables were constructed. And I somehow found time to write an article for the Southern Lumberman entitled, "Good Forestry is Good Business." I also wrote one for the Southern Pine Association, titled "Good Lumber From Second-Growth Southern Pine," the first of many articles.

The year 1937 was a banner year on the Crossett Experimental Forest (fig. 23). A 100-percent inventory of all trees by size and species was completed for the 1680 acres. After much thought and planning, we undertook a Method-of-Cutting Study. This was to compare the yields, costs, returns, and the type of stands that would develop from four different methods of cutting in the previously unmanaged second-growth shortleaf-loblolly pine-upland hardwood stands. Three plots, each 2.5 acres in size surrounded by a 2-acre isolation strip, were selected for each of four treatments:

Method 1: This involved clearcutting for sawlogs of all pine and hardwood trees 12 inches d.b.h. and larger, and for pulpwood of all pine trees 6 inches d.b.h. and larger up to sawlog size. Pulpwood was also cut from tops of sawlog trees. Hardwoods that were unmerchantable for sawlogs were either cut into chemicalwood or deadened. Such a method of treating stands was to represent a common type of treatment given the shortleaf-loblolly pine-hardwood stands by many timberland owners in the South.

Method 2: All pine and hardwood trees 12 inches d.b.h. and larger were clearcut for sawlogs. No pine pulpwood or hardwood chemicalwood was cut except from tops of sawlog trees. Unmerchantable hardwoods were deadened or cut into chemicalwood.

Method 3: This was a shelterwood cutting—cutting all merchantable trees except 15-20 per acre of the best quality pines that were 12 inches d.b.h. and larger. Remainder of treatment was same as in Method 1. This treatment was to represent a third step in intensity of treatment for the formerly unmanaged second-growth upland stands.

Method 4: This was a selection cutting—to be repeated on the same areas every 7 years. About 75 percent of the expected cubic-foot growth for 7 years would be removed at the time of each cut. Cut was to be taken from all size classes of trees, with the poorest trees removed first. The aim was to improve both the volume and quality of the growing stock. Unmerchantable hardwoods were treated in the same way as in Method 1. This treatment was to represent one of the most intensive that could be recommended to a timberland owner.

The results were most interesting. The plots clearcut to a 6-inch d.b.h. made an amazing recovery and had an appreciable stocking of pine 6 inches d.b.h. and above in 10 years, together with many hardwood stems.

Figure 23.- Part of group of foresters including the Regional Forester and representatives of his staff; the Director of the Southern Forest Experiment Station and representatives of his staff; and State and private foresters who attended an annual 2-day meeting at the Crossett Experimental Forest in April 1937. (FS 352513).

Over the first 10 years, board-foot volum growth was much the best on the selection plots but it was also surprisingly good on the treatmen #2 plots, (353 bd. ft. per acre per year, Int. ¼ inc scale). Good board-foot growth, of course, wa not expected on the clear cut and shelterwoo plots over the years. Pine reproduction wa prolific on the shelterwood plots (6,310 stems pe acre), and more than adequate on all treatments The study indicated that where a pine seed sourc is close to areas of as much as 4.5 acres, and wher some treatment is given the hardwoods, timber growing possibilities on the area are good. At th same time, the more intensive treatments paid of in a big way.

In 1937 we also started the large-scal Selection Management-Cutting Cycle Study o the Experimental Forest. In this we hoped to ge some answers to questions such as: can light frequent, selection cuttings be made in previousl unmanaged immature, understocked, second growth shortleaf-loblolly pine-upland hardwoo stands? Will this type of management and partia cutting, when applied to large acreages, permi the sawmills to be operated profitably on logs o good size and quality while the badly rundow stands were rehabilitated and their stocking quality, and growth built up? Will frequen selection cuttings increase growth enough t make up for the lower logging costs to be expecte from heavier and less frequent cuts? How wil frequent cuttings affect reproduction? Will ther be an appreciable difference in board-foot growt where the cutting cycle is relatively long o relatively short? The large-scale study, initiate in 1937, occupied twenty-four 40-acre compartments, eight of which were cut on a 3-yea cycle, eight on a 6-year, and eight on a 9-yea cycle.

The management system, as applied, favore continuous stand improvement. Within the limit of the allowable cut, the poorest and mos biologically mature stems were to be marked fo removal at the time of any cycle cut. The syste allowed for a gradual buildup of understocke stands, accelerated increment on the best trees and a gradual increase in the proportion of eac acre that would be growing large, high-valu timber.

A 3-year cutting cycle would mean that th volume of logs, and other products, removed a the time of any given harvest cut would b roughly one-half as much as for areas cut on a 6 year cycle. And only one-third as much as from a 9-year cycle. Costs and returns might, therefore, be quite different. To get a good measure of this, an elaborate recordkeeping system was set up. Changes in stand structure and growth of various products would be based on 100-percent inventories that would be repeated for each compartment at the end of each cutting cycle. To determine logging cost differences that might be present, man-hour and machine-hour costs were kept by compartment throughout the course of the study. Such figures were for cutting, skidding, loading, hauling, and overhead. Records on total volume of logs produced were kept for log size and log grade. Records on volume of pulpwood, chemicalwood, and other products produced were also recorded.

A few of the interesting results of the first 24 years of this study may be briefly summarized as follows:

1. For the quite variable previously unmanaged stands, length of time between harvest had little effect upon the total yield of high quality logs produced by the stands.

2. Total pine logs harvested while the stands were being improved and rebuilt averaged 5,654 bd. ft. (International ¼-inch scale) per acre, or 236 bd. ft. per acre per year.

3. Additions to the pine log-size growing stock averaged 4,719 bd. ft. per acre or 197 bd. ft. per acre per year.

4. Over the 24-year period pine growth in trees 12 inches in d.b.h. and larger averaged 433 bd. ft. per acre per year.

5. Pine board foot growth was equal to 8.6 percent per year simple interest.

6. Pulpwood yield averaged 1.47 cords per M bd. ft. of logs grown.

7. Pine reproduction was more than adequate on most areas although hardwood sprouts and small hardwood stems, that never had been treated, were a problem on about 10 percent of the area of study. Treatment of this brush would be desirable in the near future.

8. The increase in number of pine trees, 4 inches and larger in d.b.h., averaged 36 per acre over the 24-year period.

Thus, the answer to the major questions that we had asked at the time the study was started was "yes" in each case.

FARM FORESTRY STUDIES

About 20 percent of all forest land in the Crossett Branch territory was owned by farmers and other small nonindustrial ownerships. The

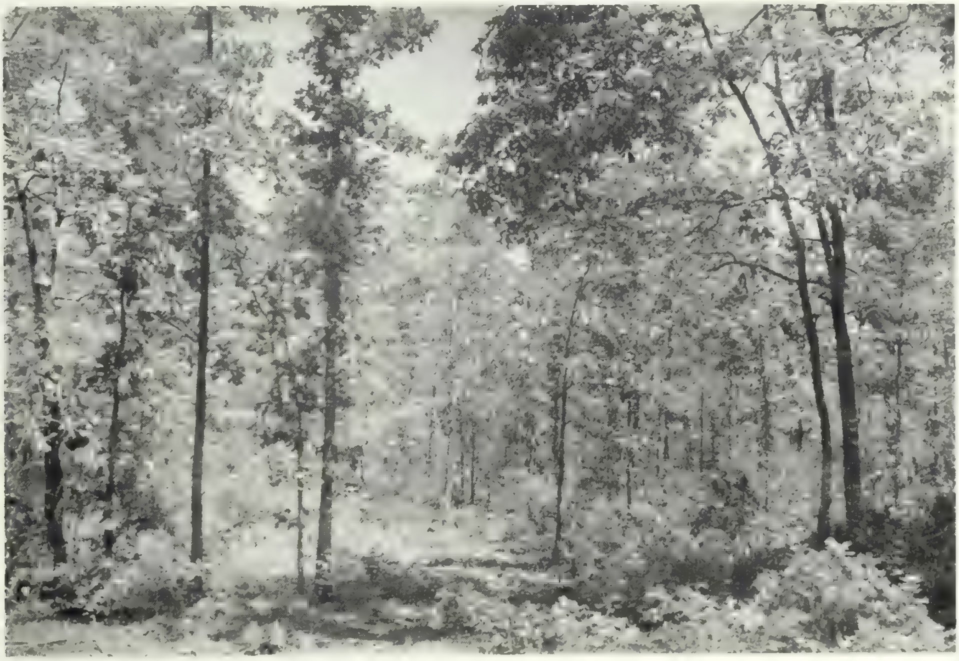


Figure 24.- Spots such as this were present on the Poor Forty when management started in 1937. Note pine in background. (FS 427241).

average per farm was about 30 acres. And, because there had been little or no market for products from such woodlands, most farmers considered it as so much wasteland. At best logs could be sold from a given area at 40- to 60-year intervals—and clearcutting of the stands was common practice.

To get farmers and nonindustrial timberland owners interested in forestry, some major changes had to be made. It would be necessary to get rid of most of the weed and cull trees, and to thin the thick patches of good trees to give the reserve stems a chance to grow at an acceptable rate. In most cases it would be necessary to increase the growing stock. Perhaps the major necessary change was to make harvests and to obtain returns from the tree crop at relatively short intervals. Could this be done?

Since farmers generally obtained returns from their row crops at yearly intervals, we decided to find out if annual returns could also be obtained from forest farming.

Consequently, one of the better stocked 40-acre shortleaf-loblolly pine-upland hardwood areas on the Experimental Forest was selected for study. Results obtained on such land might well indicate the possible returns one might get fron woodlands, once they were put in good growin condition and stocking was built up. This are was called the "Good Farm Forestry Forty." Th second area selected for study contained 34 acre of the same pine-hardwood type as the Goo Forty but was much more typical of the averag farm woodland. It was poorly stocked with pine many of which were of poor quality. It also had a abundance of cull and low-grade hardwoods up t 24 inches in diameter (fig. 24).

Annual harvests began on the Good Forty i 1938 and on the Poor Forty in 1939. To build u stocking on the latter area, the annual harves was limited to approximately 50 percent of growt for the first 13 years. By that time stocking ha increased to the point that removal of more of th growth was desirable. Consequently, the annua cut was gradually increased to a volume nearl equal to the growth. The annual cut from th Good Forty was each year roughly equal to th annual growth (fig. 25).

From 1938 to 1968, 30 annual harvests wer made from the poorly stocked 34-acre tract and 3 were made from the well-stocked area.

The number of pine trees, at the tim

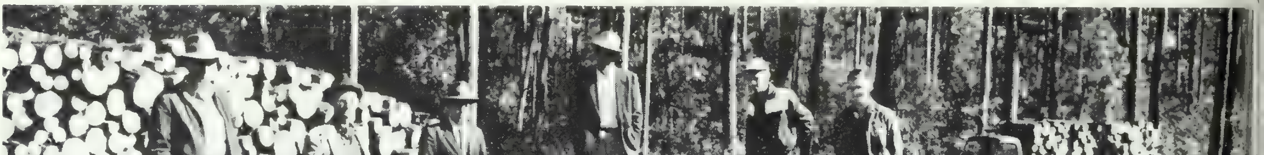


Figure 25.—Annual harvest on the Good Farm Forty. Products shown are equivalent to one year's growth on the well-stocke and managed area.

management started on the understocked area, averaged 68 per acre in the 4- to 12-inch size class and 17 in the 12-inch and larger class. Total cubic volume for trees of all sizes averaged 11.5 cords per acre. This volume included 2,341 board feet Doyle) of sawlog size material.

Over the 30-year period, 148 trees per acre were marked for cutting, 43 of which were of awlog size. Over the same period 7,420 bd. ft. of ogs, 12.1 cords of pine pulpwood and 4.7 cords of ardwood products were removed from each verage acre.

At the end of the 31 years the Poor Forty ontained 145 trees per acre in the 4- to 12-inch lass and 32 in the 12-inch and larger class. tocking of pine of all sizes averaged 23.1 cords er acre, and of this 5,323 bd. ft. was in the awlog sizes (Fig. 26).

On the Good Forty, original stocking of pine ees averaged 102 per acre in the 4- to 12-inch ass and 30 in the 12-inch and larger class. Cubic olume of pine trees of all sizes averaged 21.2 ords per acre. This volume included 5,074 bd. ft. Doyle) of sawlog size material.

Over the 31-year period of management, 91 ees per acre were marked for cutting, 36 of which ere of sawlog size. Over this period 12,160 bd. ft. pine logs, 11.1 cords of pine pulpwood, and 5.7 ords of hardwood products were removed from ach average acre.

After the 31 years of Good Forty contained 9 trees per acre in the 4- to 12-inch class and 30 the 12-inch and larger class. Stocking of pine of l sizes averaged 23.9 cords per acre, and of this ere was 7,910 bd. ft. in the sawlog sizes (fig. 7).

Over the last 15 years of the study, growth veraged better than 430 bd. ft. (Doyle) per acre er year on the Good Forty and 530 on the Poor orty.

The results from this study demonstrate the cellent possibilities of managing small tracts of blolly-shortleaf pine under the selection system r good growth and returns.

These two areas had become the most famous arm Forestry Forties in the country.

TRUCK LOGGING

The use of trucks for the hauling of logs from e woods to the railroads and mills was rapidly creasing in 1938 (fig. 28). However, the method loading these trucks left much to be desired. When an empty truck returned to the woods, one of the teams of horses used in skidding was called in to do the loading. This was very slow and tied up the truck for upwards of 30 minutes per load. Al Jacobson, forester for the Crossett Lumber Company, had some ideas on how to use the truck more effectively. He drew up plans for, and had built, some portable heavy-metal trailer-holding devices on which the log trailer could be quickly detached from the truck and held in place while being loaded (fig. 29). In the meantime, as soon as a given truck was free from its empty trailer, it could hook on to a previously fully loaded one and be off to the mill or dumping grounds in a few minutes (fig. 30). We assisted in the development and testing of this equipment.

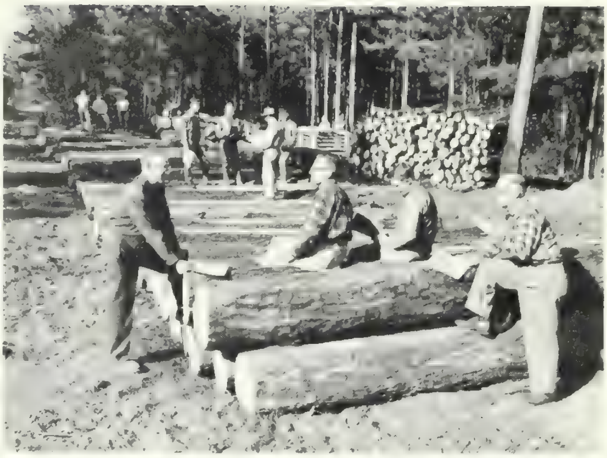


Figure 26.- The 24th annual harvest from the Poor Farm Forty. Volume of products in picture is equivalent to one year's growth on the 34-acre tract—after the stocking of trees had been increased to desirable levels.

Until the middle of 1938, it was considered unthinkable to expect that logging trucks ever could effectively deliver enough logs, and at a uniform enough rate, to meet the daily demand of a large sawmill such as at Crossett. The local foresters and some of the woods supervisory force thought that they could do this if they only were given an opportunity to try it. Because the cost of the railroad logging engines, loaders, log cars, and railroad personnel (still in use to assure an even flow of logs to the mill) was so great, it was decided to give the complete truck operation a trial at Crossett in 1939. And although there were some hitches, the use of trucks and an improved road system made it possible to supply upwards of 100 M bd. ft. per day directly from the woods to the mill. Railroad logging was "done" (fig. 31).

This was a great day for forestry and good forest management. It meant that light selection cuttings could be made from the generally understocked second-growth stands. And although the harvesting might be in progress at many different locations, the flow of logs was sufficient to maintain full-time operation of the mills. It meant that the light partial cuttings would produce logs of good average size—ones that were profitable to the mills. It also meant that the selectively cut stands could be counted on to produce greater cuts of good logs at repeated short intervals.

A WAGE INCREASE—A MAJOR PROBLEM

Looking back from today's vantage point, it is difficult to imagine that an increase of 5 cents per hour would present a "problem." However, when the Government ordered the pay scale of woods labor increased from $0.25 to $0.30 per hour, to be effective on October 23, 1939, it caused considerable consternation among officials of the southern sawmill and papermill industries. This was a 20-percent increase and the first wage adjustment in a long, long time. Many operators wondered how they would adjust their unit pay scale and selling prices.

Fortunately, the Southern Station had information available that would permit very acceptable adjustments. Because of the man-hour woods and mill production cost data obtained on the Pack Selective Logging Study, we were able to help the Crossett Lumber Company, International Paper Company, and several other companies determine what the wage increase would mean per unit of production and final product.

ITEMS OF INTEREST

In early 1939 Albin Jacobson, the fourth chief forester of the Crossett Lumber Company, moved to Fordyce, Arkansas, to become both mill and woods superintendent of the Fordyce Lumber Company. Jake had run into many major woods, mill, and personnel problems while at Crossett and had performed brilliantly. He was, to a great extent, responsible for making the conversion from railroad clearcutting of virgin timber as a source of logs for the sawmill to truck logging
selectively cut second-growth stands. He s
cessfully planned and established the Distr
System of forest management and control t
has been continued at Crossett to the present
(but with twice as many districts). The Distr
System concept and method of operation was la
widely adopted by other large lumber, pulp, a
wood producing companies. Jake also ma
numerous and continuous improvements
methods of operation in the woods and mills

He was succeeded by Norman Worthington
chief forester for Crossett. Norm was the fi
forester employed by the company.

To summarize a bit, by the summer of 1939
had largely completed the Pack Selective Logg
and Mill Scale Study and the Stand Improvem
Study. We had made good progress on the
stallation of the large Methods of Cutting Stu
the equally large 958 acre Cutting Cycle Stu
the Pine Pruning Study, and the Farm Fores
Forties. This was in addition to the large road a
building program, and the handling of the c
tinuous stream of visitors. Of equal interest
the fact that, up to 1939, the regular yea
budget of station funds for Crossett was
greater than $8,000. This included the salar
of Rawls and myself. The rest of the needed m
ey for research and construction came fr
cooperative funds, relief funds, and donatio
Because money and help were not availab
Rawls and I cruised and marked timber, dr
tractors skidding logs and pulpwood, did much
the work of establishment on the research studi
and handled visitors. On the few weekends t
we were not handling visitors, we were usually
fire detail. Seventy-hour weeks were co
monplace. What changes have taken place in
last 40 years or so!!

A LARGE-SCALE TEST OF EVEN-VERS UNEVEN-AGED MANAGEMENT

By 1941 most of the land in the 1680 acre
the original Crossett Experimental Forest
being used for research studies, a natural a
an arboretum, or for other scientific purposes.
additional forest area was needed. After m
discussion and planning, the Crossett Lum

igure 27.- Annual harvest in 1949 from the Good Forty. Group sitting on logs are (from left to right) Regional Forester Earl Stone; Chester Davis, head of Federal Reserve Board of St. Louis; Charles Grano, of Crossett Research Center; Russ Reynolds; Charles Connaughton, Director of Southern Forest Experiment Station; Lyle Watts, Chief Forester for the U.S. Forest Service; and Hamlin Williston of the Crossett Research Center.

ompany leased to the Forest Service an ad-itional 1800 acres of second-growth upland pine-ardwood land. This area was to be known as Unit 2 of the Experimental Forest. The area was ssigned to the Government on a 99-year lease for he sum total of $1.00. The lease specified that the nd and all timber was to continue to be owned y the Company, and all timber that was to be cut n the course of studies or otherwise would be ompany property. Another provision specified hat any time that the area was not needed, or sed, for research purposes, the land and timber ould be returned to the company for anagement and use.

Although there had been great, and long-isting controversy over the advantages and isadvantages of even-aged versus uneven-aged, r selection, management there had never been a ood test of the two silvicultural systems in imilar stands and at the same location. We had roposed to make such a test in second-growth hortleaf-loblolly pine-upland hardwood stands. o that the results would not be subject to question because of small plot size, we planned to use 40-acre plots and to carry out the study over a long period of time. We would use the same logging and pulpwood production crews on both even-aged and uneven-aged plots, and apply those management practices that appeared to favor each system. Half of each 40-acre plot would be managed for maximum production of pulpwood and small logs, and the other half for maximum yield of large logs with pulpwood a desirable but secondary product. Cost records in man-hours and dollars were to be kept for all stages of the management and harvesting so that results could be evaluated. This study, plus the pine-hardwood study mentioned later, was very capably handled by Charlie Grano, who had come to the station from the Ouachita National Forest whose headquarters is at Hot Springs, Arkansas.

The study got off to a fine start and gave us a chance to test an old argument. Some foresters believed that cuts of logs would be relatively light per acre under the selection, or uneven-aged system. Therefore, the logging cost would be much greater than under an even-aged system, where the volume removed at harvest time would be 5 to 10 times as much. Under the selection system, harvests of logs and some pulpwood were to be made every 5 years from a given area, and the trees marked for cutting would generally be the larger ones in the stand. Under the even-aged system, the final harvest would remove all trees of log size except for the necessary few seed trees.

The selection plots used in the test yielded a cut of about 1,200 bd. ft. of logs per acre. The even-aged plots cut to an approximate 12-inch diameter produced a cut of 6,000 to 8,000 bd. ft. (Doyle) per acre. C.C.C. boys were used to keep the daily time, cost, and yield data. The contractor doing the work said "man and boy you don't need to do this study to find out which type of cutting will be cheaper. I can tell you right now that clearcutting will be cheaper." Many interested observers had similar thoughts.

But this was not the case. The records showed beyond question that selection cutting produced logs that cost considerably less per thousand board feet to fell, skid, and haul to the mills than those produced from the much heavier cutting on the even-aged forties.

Because of the many small logs cut, the average log size from the even-aged areas was much less than those from the selectively managed areas, and the cost per thousand board feet was appreciably greater. Later studies had similar results, but this was a "shocker" to many foresters and timberland owners who thought that cheapness of logging was directly related to volume cut per acre.

PINE-HARDWOOD MANAGEMENT RESEARCH

Another important and interesting study that was started on the new Unit #2 of the Experimental Forest shortly after acquisition was one on growth, timber quality, reproduction, and returns from areas growing pure pine at one extreme to good red and white oak at the other extreme. In between were mixed stands of good oak and good pine growing together. The effect of pruning the oak was measured, as was the effect of size of opening on "feathering," or the production of new small limbs on the boles of t
oaks. This research indicated that if upland o
stands were thinned too severely, featheri
became a problem.

FARM FORESTRY STUDY DAYS

On November 2, 1942, in cooperation with t
Arkansas Extension Service, the Crosse
Lumber Company, and others, we held the first
a long series of annual Farm Forestry Study Da
on the Experimental Forest. For this and su
sequent Study Days, we made the annual ha
vests on the Good and Poor Farm Forest
Forties and stacked the products on the side of t
road at each Forty for our guests to inspect. Thu
visitors could see the large volume of log
pulpwood, and other products that could
harvested annually from second-growth shortlea
loblolly pine stands that were managed on t
selection system. A pamphlet described th
study and gave information on returns. It al
described some of the other research work, resul
of which would be applicable to the small ti
berland owners. Such studies were visited on
tour of the forest and surrounding areas. A noo
barbeque at the picnic grounds, with talks by o
or more well-known persons interested in far
forestry were other interesting events of the da

From the first, these annual "Day's" were we
attended and were a fine means of getting ti
berland owners interested in management of the
forest properties.

FIRE IN THE FORESTS

Wildfire in the woods was most certainly
major deterrent to the early attempts to practi
forest management in the South. This was pa
ticularly true for the shortleaf-loblolly pine fores
of southern Arkansas and northern Louisiana. A
was pointed out earlier, in the 1920's and 1930
most people thought that the forests had little
no value once the virgin timber had been cu

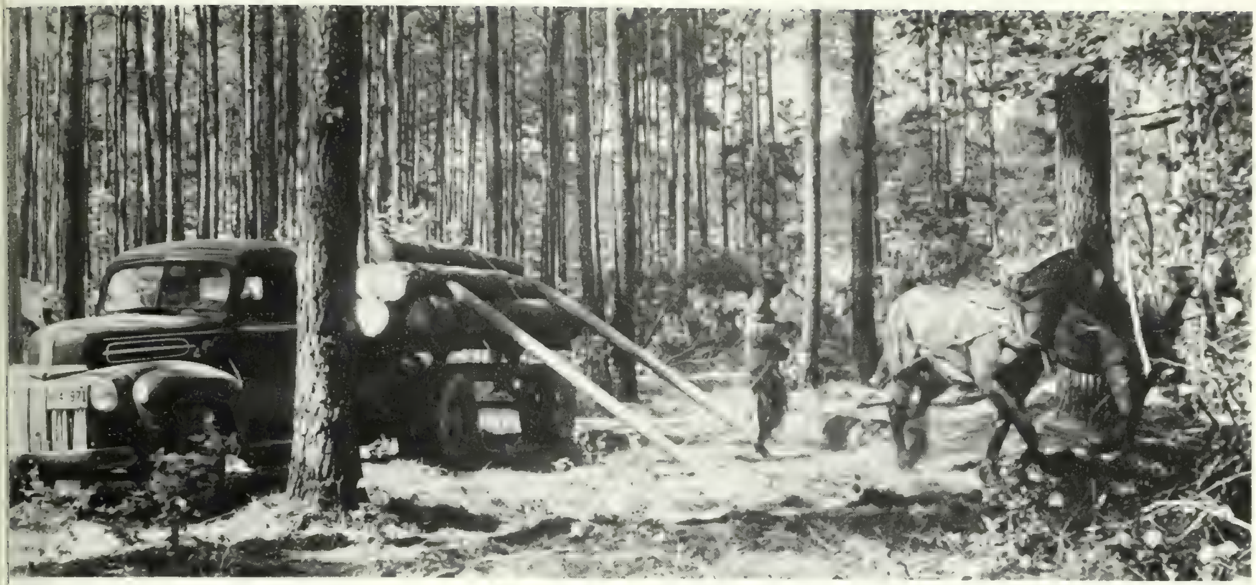


Figure 28.- Team skidding pine log into position for loading onto truck by means of chain cross-haul. This was the standard method of loading log trucks in the woods during most of the 1930's and 40's. (FS425846).

Most thought of land with trees as "unimproved land," and the only way to obtain prosperity for a given area was to remove the trees and establish row-crop farms.

Most lumber companies in the area, including the Crossett Company, were glad to sell their cutover land to those who would establish or enlarge their farms. Consequently, when management of the forests for another crop of trees was seriously considered, the area was dotted with 20- to 100-acre family type row-crop clearings. Most farmers had from a few to many head of cows, horses, mules, and pigs. The development of improved, or unimproved pastures for that matter, for grazing of these animals was almost unheard of. Livestock was turned out to graze in the surrounding "slashings" and along the roadsides. To keep these areas open and free of brush and trees, it was customary to burn over the forest area surrounding the farms. Of course, it was also necessary to burn to "keep down" the crop of ticks, chiggers, and snakes. In case some readers might wonder about the roaming livestock eating up the row crops, it might be well to report that the farms generally had fences—but these were constructed to keep the livestock "out" rather than "in."

In any event, during the spring fire season, which extended from about February 15 until the grass and other vegetation greened up, and during the fall season, from about October 1 until the winter rains started in December, woods fires would be commonplace. Many would be severe, and help needed to extinguish some of them just would not be available. It was very dry during the fall fire season of 1933 at the time that I and the 5 CCC boys were cruising and marking the first unit of the East Block virgin area for selection cutting. Fires became so general and bad that Mr. Wilcoxon, woods superintendent for the Crossett Lumber Company, asked me if I would take my crew and help out on some of them. Since the Company was paying the station for my work and the CCC program was committed to woods fire protection, we agreed to help.

The first fire that we were sent to was estimated to be 300 acres in size. At the beginning we were the first and only fire fighters working it. Looking back it seems impossible that we could get control of most of that fire. In those days there were no fire plows, no radios, no tractors, no airplanes. Our fire fighting equipment consisted of six fire rakes and two flaps. We had no backfiring torch, so when backfiring was needed, one of the men would rake up a small amount of dry grass on the tines of his rake, set it on fire, and scatter it along the fireline that had been prepared by the rakers. This would have to be repeated over and over again—often working in thick smoke—if we were trying to stop the head of a given fire. One can only imagine how tiring this continuous job of rake, rake, rake was—especially where there were vines and brush. With small crews and little equipment, about the only chance one had to stop most fires, once they had become 5 acres or more in size, was to work a considerable distance ahead of the fire and backfire from woods and county roads, and such natural breaks as streams, fields, and hardwood bottoms.

In bad fire seasons, such as the fall of 1933, the countryside would become so smoky that visibility would drop to only a few 100 feet. Under such conditions, fire towers would become useless for detection purposes. New fires would be found only by driving down the few existing roads or by reports from people living in the area.

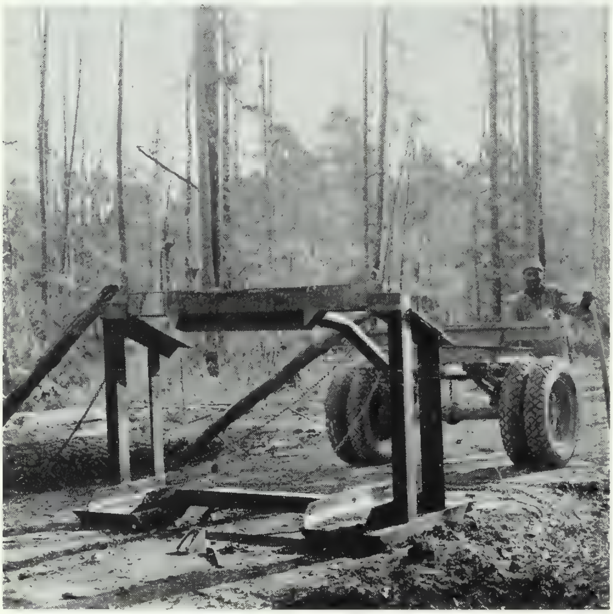


Figure 29.- Detachable log loading system developed by A. G. Jacobson. Trailer could be loaded while the truck was on its way to the mill with another load.

Under such smoky conditions, it was not at all unusual to have fires become 100 acres or more in size before anyone knew about them. The worse part of the fall 1933 fire season lasted for nearly 2 weeks after we started to help fight fire. During this period each fire that we were sent to was from 50 to 300 acres in size when we arrived. To make a bad situation more difficult, there were many "burners" in the territory. These people could be counted on to set a string of fires up to a half-mile or more in length on bad days, and to immediately set new fires as soon as the fire crew left. They even sent word to the fire protection force that they would set fire on a certain day and in a certain location. Most of these "burners" were good woodsmen and were hard to catch in the act of setting the fires, especially when they rode horses and kept off roads. Adding to the problem was the fact that, when the burners were caught, the courts either turned them loose, or fined them $10 at most.

THE BEGINNING OF STATE FORESTRY IN ARKANSAS

As of 1930 Arkansas was one of the largest timber producing States in the Nation. At the same time it was the only State that had a major forest fire protection problem but no forestry department. The various lumber companies who wished to protect the regrowth on their cutover timberlands had to provide protection entirely on their own.

The 1931 session of the Arkansas Legislature passed Act 234, which created the State Forestry Commission. However, neither the 1931 nor the 1933 session made an appropriation, so the Commission could not become active. Finally Governor J. M. Futrell decided to act and asked for a public subscription of $5,000. He received $7,805, and the Arkansas State Forestry Commission came into being. It employed Charles A. Gillett as State Forester. The State was broken down into units, with each unit under the supervision of a district forester. Curtis Coffman was in charge of Unit #1 with headquarters at Hamburg. J. O. Lee supervised Unit #4 at Warren, and Louis Ramsey supervised Unit #3 at Fordyce. It was generally understood that, for successful management of the forest, fire protection was the first consideration. As of June 30, 1934, the Commission had about 2.5 million acres under "intensive" protection from fire, all of which was in southern Arkansas. Most of the effort was made possible by timberland owners who contributed two cents per acre per year, for a total of about $26,000.

Establishment of the Forestry Commission did not alter the fact that there were few fire towers. Communications were very poor, and the fires were to be fought by local "guards" using fire rakes and swatters.

igure 30.- *Truck backing into position to pick up a load of pine logs that had been loaded on the trailer while the truck had taken another load of logs to the mill.*

Fortunately for forestry, perhaps the biggest oost to the early efforts at establishing timber anagement in the region was the Emergency onservation Work Program, the CCC. A 200-an camp was established in Ashley County—rst east of Crossett, then moved to Hamburg.

Under this work program, only work of a ublic nature could be done. However, the law ermitted work on private land which the state ad agreed to protect under the provisions of the lark-McNary Law. It was this large amount of vailable manpower—with fire rakes—that kept e losses to wildfire within reasonable limits. Of urse, the CCC's accomplished much other very aluable work directly relating to forest anagement. They built steel lookout towers; lephone lines to establish communications etween towers, and between district eadquarters and the towers; and constructed any miles of truck trails and many bridges.

Because of lack of funds, the CCC camp at amburg was discontinued in late 1935. What a low! Arrangements were made to obtain help om the CCC camp at Monticello, which had been onsored by the Soil Conservation Service, but ch assistance was always uncertain. Sometimes e crew would have orders to return to camp at a rtain time regardless of progress—or lack ereof—on a given fire. Often the companies had use their woods, bridge, and road crews to help. any small timberland owners also helped.

In the spring of 1936, District Forester Coffman moved from Unit #1 at Hamburg to a new Unit #14 at Hardy, Arkansas. J. C. (Custer) Ross replaced Coffman at Hamburg.

A major step toward freeing forest fire control from almost complete dependence on the fire rake was made during 1936 at Crossett. Based on ideas conceived by Glen Durell, assistant State Forester in charge of fire control, Ross, with the help of a good mechanic and welder, developed a completely new tractor-powered fire-trail plow. It differed from those in limited use elsewhere in the country in that the plow was attached to the front and was pushed rather than pulled by the tractor. With the plow in this position, the operator had a clear view both of the plow and the country over which it would pass. It, therefore, relieved the driver of the strain of frequently taking his eyes off the terrain ahead to manipulate the plow behind.

The first time that a tractor-plow was used on a fire in Arkansas was on the "Honeycutt Barn" fire north of Crossett in August 1936. The plow showed great promise, and with some modifications soon began to perform excellently.

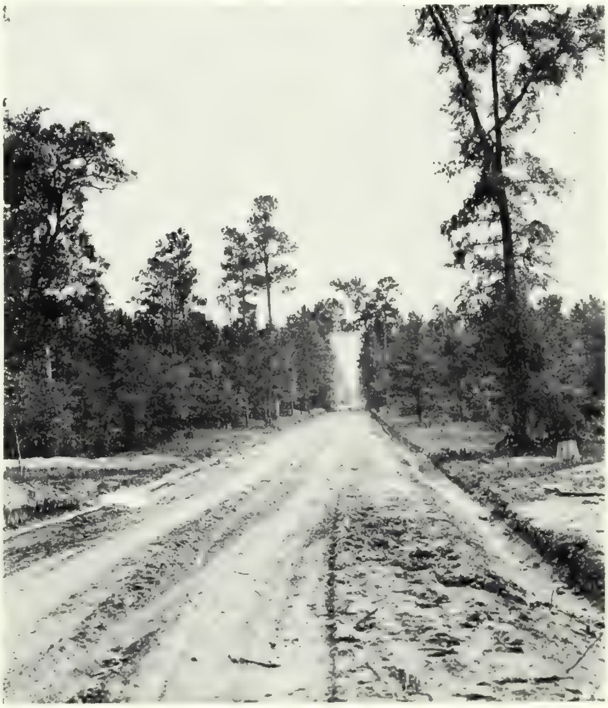


Figure 31.- *First truck trail constructed by the Crossett Lumber Co. The trails permitted frequent light cuts of pulpwood, chemicalwood, sawlogs and other products.*

Once the special trucks and truck beds, on which the tractors could be self-loaded and self-unloaded, were constructed, these fire plows became the "work-horses" of the fire protection forces. When called for they could arrive at a fire as quickly as a crew of men, and could do much more work without getting tired. The main drawback was the lack of funds with which to purchase more than a plow or two for each Unit. So, the use of fire rakes was standard practice for many years after the fireplow came into the picture.

FIRES AND THE CROSSETT RESEARCH CENTER

Crossett Lumber Company officials once admitted that one reason they wanted the Government to locate in the general vicinity of what is now the Crossett Experimental Forest was because of the fire problem in the area. Three suspected woods burners lived in the area, and it was thought that the presence of Federal people would greatly reduce incendiarism.

In any event, at the time that the Crossett Research Center and the Crossett Experimental Forest were established, fire protection of the area was considered a must for research to be effective. During work hours we had a good supply of manpower for any fire fighting job that might show up. But after work hours—nights, Saturdays, Sundays, and holidays—the detection and much of the fire fighting job fell upon the shoulders of Ike Rawls and myself. If a fire was in progress and it was too large for one or two men to handle, we could call upon some of the W.P.A. foremen—if we could get word to them. But most of them lived far from the Experimental Forest and most could not be contacted by phone. So we did our best to keep every fire small. This meant constant watch of the area when the local firetower was not manned, including driving the roads and trails at night when winds were high and/or humidity was low. Hundreds of nights we made regular inspections of the area until midnight or later, looking for "lights" and sniffing for fresh smoke.

Up until the time houses were built at station headquarters, one of us remained on the area until dark to watch for smokes. On one such late afternoon in the spring of 1934, I was in a car parked on the highway, when I saw a big puff of black smoke about a half-mile away and not too far off one of our newly-constructed forest roads. I quickly cranked up the car's engine and dashed to the area, but when I got there, no smoke was to be seen. I went back to my parking spot, and soon the smoke appeared over the treetops again. I went back and, could find neither fire nor smoke. By then it was dark so I went home.

Figure 32.- Custer Ross, developer of the push type fire plow and the use of planes for forest fire protection

Several days passed before we found the answer to the mystery. In a sheltered and shaded spot on a small intermittent creek that ran through the area, we found an old copper boiler, two washtubs and a dipper, plus a good supply of fat pine knots. One of our neighbors had a private still where he was making "white lightning." The big black smoke that I had seen was caused when the "brewmaster" had put some more pine knots on the fire. When he heard the car coming toward him, he quickly grabbed a pail of water and doused the fire. When I left the general area, he fanned the fire into life again and threw on some more pine knots.

After my second trip down to this area, he apparently decided that I was a persistent cuss, so he took most of his good equipment and moved to a safer location.

With the increased attention, and money, given to the reduction of forest area burned by fire came the need for an improved fire danger meter for determining the amount of fire danger on a given day. Starting in 1941, Crossett researchers began a series of tests on various indicator materials for use in accurately determining oisture content of grassy and woody fuels. Over he years, many improvements were made in such eters, but every time higher authority at-empted to establish "universal" meters it was lways found that the meters needed to be ad-usted for local conditions. This subject at times eveloped great controversies, and never was ettled to everyone's satisfaction.

THE BIRTH OF AERIAL PATROL

The fireplow, danger meters, and an expansion the telephone system served well in reducing reage losses from fire. Yet, protection efforts ere seriously hampered during those periods hen smoke from many fires reduced visibility to miles or less. Such conditions developed quite ten, and when they did the towers were almost eless.

The use of planes for detection on hazy and ggy days was discussed as early as 1939, but anes were hard to come by and had never been ed for this purpose. District Forester Custer oss should be given most of the credit for the troduction of the airbird for detection purposes g. 32). With approval of State Forester Lang d the State Commander of Civil Air Patrol, he ade arrangements with the C.A.P. unit located El Dorado, Arkansas, to furnish a plane and ot to make some test flights over the Ashley d Drew County areas on days with low ibility. The pilots of the planes were also the servers and made a note of the general location each smoke found. Upon landing back at the se in El Dorado, they would call the Crossett vision Forester and give him their report. cation of fires were tied in to some well-known dmark such as "about 3 miles southeast of ossett."

Use of the Civil Air Patrol planes for fire ection on bad days was continued until 1944, en A. E. Jennings became manager of the ossett Airport. At that time, the Forestry mmission made arrangements with him to fly of his two planes on days when visibility was . He was not acquainted with land lines and d descriptions, so it was necessary at first to ve a "spotter" fly with the pilot. The spotter s usually District Forester Ross.

This new detection tool immediately proved very valuable, not only for locating fires on days of low visibility but also for directing crews on large fires. Up until the introduction of the planes, communications on going fires had to be by "runners" or "on the ground" inspection. Thus, the man in charge of the suppression forces often had to more or less "work in the dark." Much additional acreage was lost, because it took many precious minutes to get word of a "breakover" to the fire protection forces working on another part of the fireline.

The one stumbling block in the use of aerial detection was the fact that the observer in the plane had no means of instant communication with people on the ground. In the first few months, the pilot had to land and telephone the location of new fires or other information to the ground forces.

This bottleneck was solved, to a great extent, by the use of empty quart oil-cans and empty ice cream cartons with streamers attached. The observer in the air would write his message on a piece of paper, put it in the container and drop the missile to a waiting crew. It was not long before fire protection forces elsewhere adopted this technique.

Short-wave portable radios came into being in the mid-1940's, and by 1947 radio networks with fixed stations proved extremely valuable in the fire-protection battle.

CONTROLLED BURNING

In the early days of the new forestry movement, it was universally shouted that all fires in the woods were bad. But, for some time, naval stores (turpentine and rosin) operators in the longleaf and slash pine areas of the Gulf South had been burning over large areas of their holdings each year to make sure the wildfires would not wipe out their operations.

After several large wildfires did tremendous damage to their stands, many large (and small) timberland owners in the Southeast also began using "controlled" fires, during safe periods, to reduce the amount of burnable material on the ground (the rough) and to keep the stands "open" and relatively free of brush and vines.

Largely because of pressure brought by H. H. Chapman and a few others who claimed that controlled fire should also be used in the shortleaf-loblolly types, the Forest Service began many studies to determine how fire affected the forest. These studies included the effect on soil, brush control, damage to existing trees, release of soil nutrients, and other factors. Working under the leadership of Al Bickford, who headed up fire research at the Southern Station, the Crossett Branch began a whole series of controlled burning studies starting in the spring of 1941.

Among the early results from these studies was the finding that successful controlled burns required about the same fuel and weather conditions as those found on the average hot uncontrolled fire; a good supply of dry grass and/or needles and leaves, low relative humidity, and a good steady wind. Under such conditions the fires will kill the aboveground portions of most small hardwoods and vines. However, except for dangerous summer fires, or those that burn during very dry periods, few of the hardwood rootstocks were killed. A great many recovered and from one to a dozen new stems would show up for each stem "killed." Even a number of repeat fires in later years did not kill a majority of the original rootstocks.

The controlled burn, or repeat burns, did, however, retard the recovery of the hardwood brush. When a pine seed source was available in the first year or two after the burn, and the overstory was not too dense, a satisfactory stand of pine seedlings did become established and beat out much of the recovering hardwoods for a dominant place in the new stand. Sometimes the pine seeded in to such a dense stand that it would likely stagnate before the stems would reach a merchantable size for any product. Thus, removal of the surplus pine and the sprouting and competing hardwoods was a likely necessity.

The controlled burns usually did not kill hardwoods above 2 inches in diameter and where desirable these had to be deadened by other means.

Most fires that were effective in killing the above-ground portions of the unwanted hardwoods killed most of the pine seedlings and the pine saplings up to about 15 feet in height. Thus, any area to be burned that contained patches of young pine that were to be saved, had to be protected by fire lines.

Controlled burning of older pine stands on days when temperatures were high and humidity was low resulted in much crown needle scorch and a appreciable reduction in tree diameter and volume growth.

COOPERATIVE RESEARCH

Regular Federal funds for an expanded program of forest research continued to be nearly nonexistent in the 1940's. To stimulate more effort, the assistant chief for forest research in the Washington office urged field Branch Station Leaders to encourage additional cooperative funds from timber owning companies. It was promised that any private funds so obtained would be matched by additional Federal research funds. John Watzek, an owner and director of the Crossett Lumber Company, also responded to our request by offering a sizeable sum of Company money to finance a program on genetics research on loblolly pine.

Such a program began at the Crossett Branch in 1951. This was one of the first major genetics projects in the South. Much of the work was on large-scale loblolly pine seed source tests, and on selection and breeding of "plus" trees. Roland Schoenike headed up the program in the beginning and was followed by Hoy Grigsby. Wonderful cooperation in the form of manpower, land and timber, equipment, and plantation areas was provided, not only by the Crossett Company but the Fordyce Lumber Company, Southern Lumber Company, International Paper Company, Continental Can Company, and many other companies and individuals.

About this same time, the need for information on water requirements of managed stands of loblolly and shortleaf pine became apparent. We had many questions. For example: What was the water holding capacity of the various soils in Arkansas, Texas, Louisiana, and Mississippi? How much was required for maximum growth of the stands? How much of the available water was used by dense stands of understory brush? Would fertilizers produce an appreciable increase in growth of young and middle-aged stands?

Again we sought help from the various timber wning companies in south Arkansas and north ouisiana, and they came through with funds. mong the companies contributing cooperative nds were Deltic Land and Timber Company, nternational Paper Company, Ozan Lumber ompany, and Fordyce Lumber Company.

This line of research, also was the first in the gion, and yielded much valuable practical in-rmation at an early data. Robert Zahner headed p this research for several years.

It was found that the silt loam and silty clay am soils found in much of the pinelands of utheast Arkansas and northeast Louisiana ould hold up to 14 inches of water in the top 4 et of soil. Some of the sandy soils would hold ly 3 to 6 inches in what was considered to be the ot zone.

A reasonably well-stocked stand of trees ould use about 2 inches of water per month at e beginning of the growing season. This use creased rapidly to 7 inches (if available) by the st of July and continued at a high rate through the rest of the summer. Late spring rainfall, as well as precipitation throughout the summer and fall is usually less than the stand of trees can use so by early May the trees start drawing water out of their root zone "water tank." By the last of June available stored water is largely used up. Thus subsequent diameter and volume growth depends upon current precipitation for the rest of the growing season. Heavily stocked stands rarely grow more than half of their potential volume of wood because of lack of water.

ure 33.- A sudden-sawlog study plot thinned to 100 trees per acre at age 9.

Any green growing thing in the forest needs water to live and develop. This includes not only the desirable trees but also the cull trees, hardwood brush, vines, surplus reproduction, and surplus trees of all sizes. All draw water out of the limited amount in the "water tank."

In one case it was found that reducing the volume of growing stock trees from 100 or more square feet per acre, to 50-60 square feet allowed the trees to add growth all through the growing season instead of for only a portion of it. This was true because there were many fewer stems drawing water from the limited amount in the root zone supply. Likewise studies proved that reducing or eliminating a large proportion of the dense understory brush would result in a large increase in the growth of the overstory pine.

Fertilizer studies indicated that nitrogen was the one element whose addition would produce the greatest growth response from the pine timber stands in the Crossett Research Center territory. But the response varied from one soil type to another and it was temporary. Usually increased growth could be expected for only 3 years. Younger stands had greater responses to fertilizer applications than stands of older trees.

Considering how much fertilizer had to be applied to have an appreciable effect on growth and the high cost of the application, the practice was not practical at the time.

THE "SUDDEN SAWLOG" STUDY

Another study that was a Crossett Branch "first" was the "Sudden Sawlog" study with loblolly pine. The generally accepted criteria for full, or normal, stocking of managed stands in the earlier years was always 120 or more square feet of basal area per acre. Such stocking might well produce the maximum amount of cordwood growth per acre, but the diameter growth of individual trees was slow and the stands often had to reach 40-60 years of age before an appreciable number of stems would contain usable volumes of sawtimber. Even in the earlier years, the value of a cubic foot of wood in a sawlog was much greater than the same cubic foot in trees of pulpwood size. Thus, it seemed reasonable to assume that, if the planted or natural stands could be thinned severely so that there would be very little competition between trees, for soil moisture and sunlight, the trees would reach sawlog size at a much earlier age. It was very likely that, with additional thinning, the return in dollars per acre per year would be appreciably more for the heavily thinned than the “fully stocked” stand over any reasonable number of years.

In a 1954 study to test such possibilities, a fully stocked plantation (6 x 6 feet) was thinned back to 100 trees per acre at 9 years of age (fig. 33). This was compared to a treatment in which the stand was thinned back to 85 square feet of basal area (712 trees) at age 12. The plots in the second treatment were thinned back to 85 square feet at the end of every 3 years. The heavily thinned plots were also given additional thinnings as diameter growth slowed or crown competition developed.

Other treatments were included in the study to see if leaving more than the 100 crop trees for a few years would boost total yields. But such treatments were only a slight variation of the original objective.

Trees on the heavily thinned plots averaged from 16 to 17 inches in diameter at 30 years of age. The trees on the plots thinned in a manner that would be considered heavy thinning (to 85 square feet of basal area) at the time, averaged 11 inches in diameter at 30 years.

Sawtimber yields, including material removed in thinnings, averaged approximately 10,000 bd. ft. per acre (Doyle) at stand age 30 for the plots originally given the very heavy thinnings. This compared to about 3,200 bd. ft. per acre for the plots repeatedly thinned back to 85 square feet.

Total yields in cubic feet to age 30, including material removed in thinnings, for the plots thinned back to 100 trees per acre averaged a proximately 3,200 cubic feet per acre as compa to nearly 4,700 cubic feet for the plots give more standard type of thinning. However, greater yields in cubic feet would be of great interest to owners of pulp and paper compan because a large proportion of the production co only be sold as pulpwood, at a much lower rate cubic foot than material in trees that were la enough to produce logs.

At $150 per M bd. ft. (Doyle) the hea thinned plots produced a return of about $1, per acre at 30 years.

The value of the 3,200 bd. ft. produced on less heavily thinned plots was appraised at $ per M bd. ft. because the logs averaged m smaller in size than on the 100 tree per acre pl The total value of the logs produced were ab $320 per acre at age 30. However, these pl would have produced about 40 cords of pulpwo in addition to the logs, and this at $6 per c would have been worth about $240 per acre. Th the total value of the production would have b $560 per acre or only about 31 percent of the va received for the “Sudden Sawlog” plots.

IN CONCLUSION

Many other interesting and important fores related events took place in the south Arkans north Louisiana area during the 1930-1 “Beginning of Forestry Years.” Many ot important research studies that were first in th field were undertaken at the Crossett perimental Forest and on company timberla during this same period. Many other U.S. For Service and Arkansas Forest Commission sonnel and many individuals—from Chairmen the Board down to field hands—helped in gett forestry launched in those early and format years. To attempt to name them, and th contribution, would require much space invariably some would be overlooked. So, to who should have been mentioned but were my apologies.

It was a most interesting period.

Reynolds, R. R.
1980. The Crossett Story: The beginning of forestry in southern Arkansas and northern Louisiana. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-32, 40 p. South. For. Exp. Stn., New Orleans, La.

A history of the establishment and early work of the Crossett Experimental Forest and Research Center.

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U.S. Department of Agriculture
Forest Service
General Technical Report SO-33

Harvesting Energy Chips from Forest Residues—Some Concepts for the Southern Pine Region

Peter Koch

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SUMMARY

Residues from southern forests include tops, branches, central root systems, brush, cull trees, trees of unmerchantable species, and trees too small for economic harvest by conventional methods. Before such residues can be used by industry to produce energy, they must be reduced to chip form and delivered to mill stockpiles at a cost that will permit proposed wood-energy processes to operate competitively. Processes, for which wood chips are the feedstock, include combustion, gasification, pyrolysis, liquefaction, and hydrolysis and fermentation.

This paper describes and illustrates about a dozen harvesting methods which can be classified according to procedure as follows:

- Chip whole trees at the stump.
- Extract sawlogs at the stump; bunch and forward branches.
- Chip whole trees at the landing.
- Extract sawlogs at the landing; then chip, chunk, or bale branches.
- Chip residues at the mill.
- Transport complete trees to the mill (stem, crown, roots, and foliage); at mill, divert tree portions to use of highest value.

The cost of energy chips delivered into mill stockpiles, including 30-percent pre-tax profit on harvesting investment, will likely range from $18 to $33 per ton (green-weight, 1980 basis).

1980

Harvesting Energy Chips from Forest Residues—Some Concepts for the Southern Pine Region

Peter Koch

INTRODUCTION

This report on procedures for harvesting south- rn forest residues is a companion publication to previous report (Karchesy and Koch 1979) on ethods of producing energy from hardwoods rowing on southern pine sites.

Forest residues from southern pine sites include ps, branches, central root systems, brush, cull ees, trees of unmerchantable species, and trees o small for economic harvest by conventional ethods. Before such residues can be used by dustry to produce energy, they must be delivered mill stockpiles at a cost that will permit oposed wood-energy processes to operate com- titively. Usually the residues must be reduced chip form.

While much of the total residue volume per re is in stump-root systems (fig. 1), and some in small pine culls and pine logging slash, e preponderance of the volume is in unmer- antable and cull hardwood trees. Such trees are pically small in diameter, short, and crooked. w volume per stem and per acre and highly riable species mixes from site to site and from and to stand combine to raise harvesting costs. ve of the major species, sweetgum, black tupelo, llow-poplar, sweetbay, and sugarberry, have un- vided central stems typical of excurrent growth. g. 2, left); this growth pattern eases harvesting oblems. Sixteen of the species (the oaks, hickories, ns, and red maple), however, have forked stems pical of decurrent growth (fig. 2, right) that ke harvesting them difficult and costly. The ash ecies are intermediate in growth form, but have dely spreading crowns.

Moreover, many pine-site hardwoods grow on rain that is ill-suited for harvesting equipment. amples are the steep, rocky slopes of the Arkansas and Virginia mountains, and the soft ground of the rain-saturated, rock-free, flat-to-rolling coastal plains in winter.

Proposed in this paper are partial solutions only, and some concepts for consideration. Significantly increased research and development work on logging systems and equipment appropriate for the resource are essential to fully adequate solutions (Boyd et al. 1977). Such work should be carried out at numerous centers because failures will outnumber successes. The rarity of technological breakthroughs over the decades attests to the difficulty of developing efficient harvesting techniques for the pine-site hardwoods.

Harvesting methods are influenced not only by terrain features, soil characteristics, weather, and ecological considerations, but also by stand density, diameter distribution, species mix, scale of the harvesting operation, tract size, and the purpose for which the trees are logged, i.e., for fuel, pulpwood, solid wood products, or chemical products. My initial assumption—that energy wood will usually be delivered to the energy-producing plant in chip form—somewhat defines harvesting procedures.

Processes, for which wood chips are the feedstock, include combustion, gasification, pyrolysis, liquefaction, and hydrolysis and fermentation.

This paper describes and illustrates about a dozen harvesting methods that can be classified according to procedure as follows:

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ter Koch is Chief Wood Scientist, Forest Products Utilization Research, Southern Forest Experiment Station, Forest rvice—USDA, Pineville, Louisiana. This report is based on a paper presented at the Weyerhaeuser Symposium "Forest-t Mill Challenges of the Future," Tacoma, Washington, September 17, 1980.

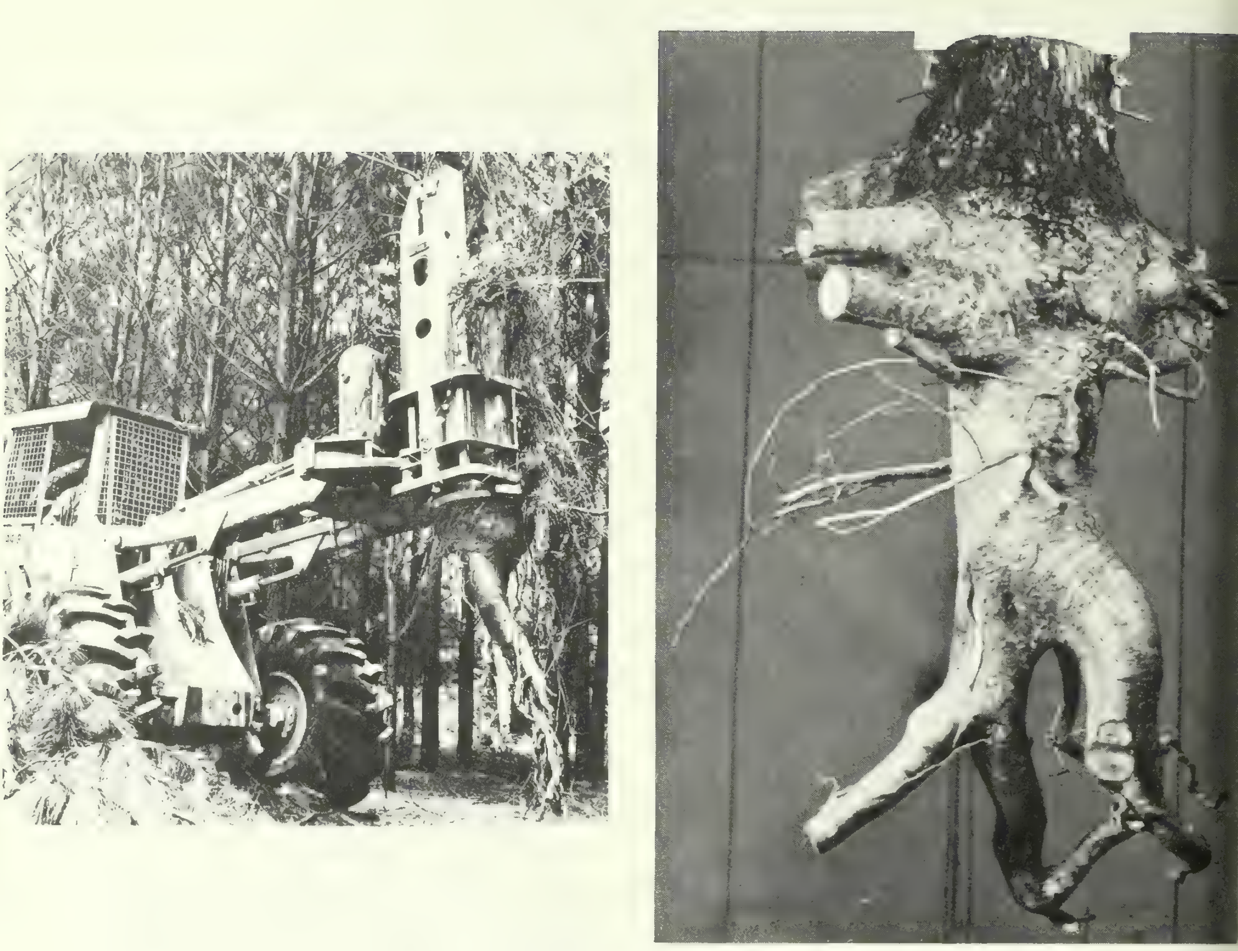

Figure 1.—*Central stump-root systems. (Left) Southern pine. (Right) Sweetgum.*

CHIP WHOLE TREES AT THE STUMP

The problem of accumulating logging slash, or pine-site hardwoods with their widespread strong limbs, into compact bundles for skidding or cable yarding is difficult; chipping whole trees at the stump is one alternative.

Felling-bar harvester.—Five timber companies with southern operations and Nicholson Manufacturing Company cooperated with the Southern Forest Experiment Station of the U. S. Forest Service (with substantial financial assistance from the Department of Energy) to develop a commercial prototype of a swathe-felling mobile chipper. From many proposed designs, a mobile chipper with a ground-level cylindrical felling bar feeding a drum chipper was adopted (fig. 3).

Performance goals required that the chipper:

- Operates primarily on terrain that is relatively stone-free, has a slope of 30 percent or less, and supports 9 psi in track pressure. In follow-up designs, a track pressure of 8 psi will be the goal; 6 psi would be preferable.
- Harvests 1 acre per hour at 1 mile per hour on land averaging 25 tons (green weight) of logging residue and standing culls per acre.
- Fells and chips standing stems of southern hardwoods and softwoods up to 12 inches in diameter (measured 6 inches above ground level) while moving at 1 mile per hour.
- Mills off the tops of 12-inch-diameter stumps to 6-inch height while traveling at 1 mile per hour (larger stumps at lower speeds).
- Picks up and feeds into the drum chipper tops, branches, and cull stem sections residual from logging operations.
- Chips felled stems up to 19 inches in diameter if properly oriented to the chipper infeed and with heavy lateral branches severed or notched to ease crown compaction.

The commercial prototype was assembled on the chassis of an FMC forwarder equipped with extended tracks (fig. 4, bottom). The machine has a 575-horsepower diesel engine which powers all functions including propulsion. Specifications are as follows:

Gross vehicle weight	73,000 pounds
Approximate ground contact area with 2-inch penetration of tracks	6,740 square inches
Approximate ground pressure	10.7 psi
Drum chipper characteristics	
Cutting circle diameter	48.0 inches
Spout width	47.5 inches
Number of knives	3
Rake angle of knives	52.5°
Drum speed	544 rpm
Nominal feed speed	136 feet per minute
Felling-bar characteristics	
Cutting-circle diameter	16.5 inches
Length	93.5 inches
Number of knives	4
Rake angle of knives	38.5°
Rotational speed	0-600 rpm
Clearance above ground	2 to 7 inches
Diameter of side feed rolls	24 inches
Machine ground speed	Creeping to 3 miles per hour

In operation, chips from the drum chipper are lown to the rear of the moving machine into ne of a pair of self-powered tracked vehicles, ach carrying a quick-dump chip bin with 10-ton olding capacity (fig. 4, top). Average speed of the nobile chipper should be 1 mile per hour over ock-free terrain of less than 30-percent slope hat will support 10 psi ground pressure. At this peed the harvester will cover about 1 acre per hour n land averaging 25 tons (green weight) per acre logging residues in the form of tops and limbs, tanding cull trees, and stumps. About 85 percent such residue should be recovered as chips and elivered into roadside piles at about $11.85 per reen ton including 30 percent pretax profit on quipment investment (1977) of $470,000. When cheduled 7 days a week and 9.5 hours a day, the achine should harvest about 1500 acres per year Koch and Nicholson 1978).

If this system can be put into successful operaon, it will provide mills with wood for fuel and ber that would otherwise be wasted; the system so has numerous other benefits:

- Changes some of the capital investment for site preparation to a harvesting expense.
- Should improve public reaction to harvesting because it eliminates waste wood and unsightly slash.
- Avoids the smoke of windrow and burn operations.
- Compared with the windrow and burn system, increases plantable area (by perhaps 10 percent)—because not all windrows are completely burned.
- Increases land productivity, because scalping inherent in pile and burn operations is eliminated.
- Hastens replanting by several months because harvesting accomplishes site preparation.
- Wood harvested is forest residual chips (rather than chunks or shreds) which have high potential for fiber products more valuable than energy.
- Because no wood is skidded over the ground, wood delivered via mobile chipper and chip forwarding bins should be relatively free of dirt.

The swathe-felling mobile chipper equipped with felling bar is currently undergoing extensive tests on southern lands of the U.S. Forest Service and the five industrial cooperators. Performance data should be available in 1981.

Circular-saw harvester.—An alternative design for a swathe-felling mobile chipper severs stems and feeds a disk chipper with dual ground-level circular saws counter-rotating toward each other (Smith and O'Dair 1980). NFI, Inc., Alexandria, La., cooperated with Georgia-Pacific Corporation to build a brush harvester on this principle (fig. 5). All functions of the harvester are driven by a 430-horsepower diesel engine. The tracked machine weighs 48,000 pounds when carrying a 6,000-pound chip load and exerts a ground pressure of 8.3 psi. The 16-tooth cutter disks remove a 2¼-inch kerf and cut a 7.5-foot swathe. Trees and brush 5 inches in dbh and smaller are easily felled and efficiently fed into the chipper. Design ground speed is about 1 mile per hour. The machine as originally built was priced (1978) at about $245,000, and had hourly production of about 6 tons (green basis) of whole-tree chips.[1] The machine illustrated in figure 5 must cease harvesting each time the

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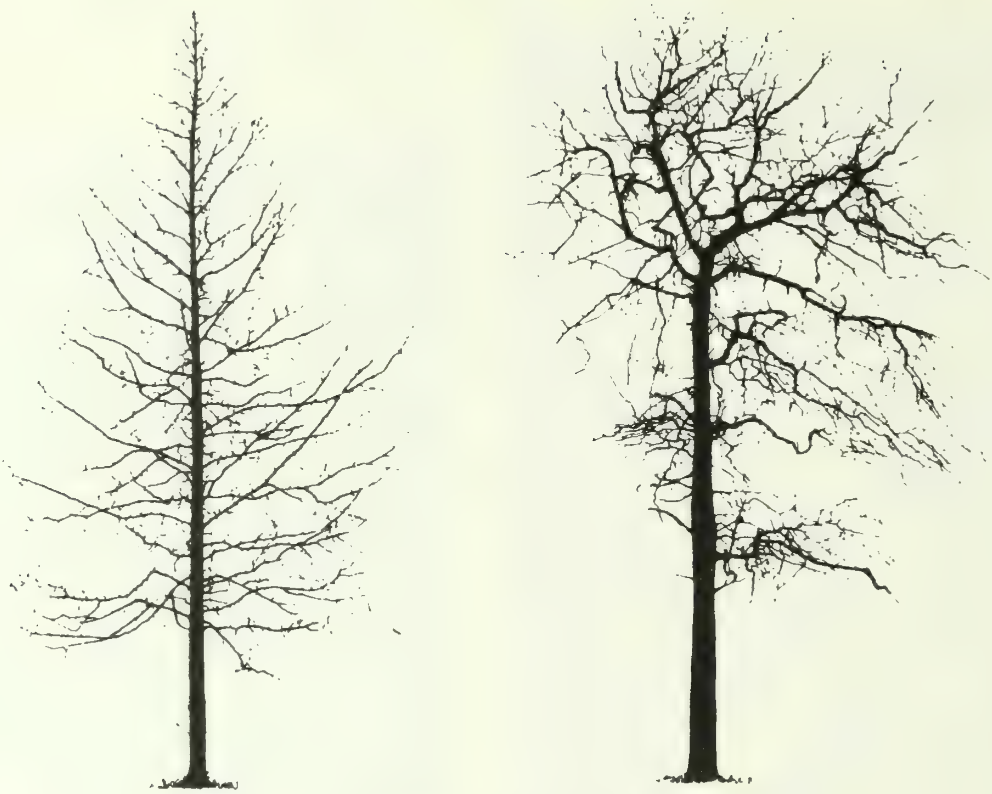
[1] Koch, P. 1977. Correspondence relative to Study FS-SO-3201-2.81, Southern Forest Experiment Station, USDA Forest Service, Pineville, La.



1-Foot Radius Lateral Root System

Tree Part	Percent
Foliage	**3.2**
Branches and Twigs	**18.5**
Stem	**63.0**
Stump-root System	**15.3**
	100.0

Figure 2.—*Typical stem and branch patterns, and average biomass distribution (dry-weight basis) of 6-inch diamet hardwoods of the major species growing on southern pine sites. (Left) Excurrent growth of sweetgu (Right) Decurrent growth of blackjack oak. (Drawings after Brown and Grelen 1977.)*

chip bin is filled, travel to roadside to empty its load onto a roadside chip pile, and then return to where harvesting was discontinued.

To avoid such discontinuous harvesting, the Pallari harvester, which operates on a similar felling and chipping principle (fig. 5A), discharges chips into portable chip sacks which are thrown from the harvester when filled. Use of sacks gives the harvester maneuverability around obstacles and enables it to reverse; also it permits formation of a small buffer storage in the forest. Disadvantages include additional original investment in sacks and costs of sack repair; also the sacking system requires at least one extra hand for the harvester and another for unloading sacks roadside. Readers interested in the system a referred to Hakkila and Kalaja (1980) who hav provided operational data on the machine.

Manual felling and farm-tractor chipping.—Th systems just described use complex heavy machi ery involving substantial investments. There a simple alternatives requiring less capital but mo labor. For example, using light farm machine (fig. 6) a man can harvest during 1 working da about 4.3 tons of green whole-tree chips equal fuel value to 1 ton (286 gallons) of oil. (A gallo of number 2 heating oil weighs 7.0 pounds and h a heat content—135,000 Btu—equal to about ounds of green whole-tree chips of pine-site hardoods.) At $1.00 per gallon, 286 gallons of heating il (1 ton) will cost $286.

The poorer burning efficiency of wood, the high ost of wood-fueled burners compared to oil burners, nd the inconvenience of handling wood make it oubtful that a seasonal worker could sell his ay's output (4.3 tons of green chips) for $286, ut he might—in the not too distant future—get 143 (or $33 per ton) delivered to the user's el pile.

The low-investment harvesting shown in figure 6 ould be ecologically acceptable to many southern rmers and woodlot owners. Each worker in the vo-man team might earn $143 per day, less his are of stumpage, daily cost of the chainsaw and mple harvester, and cost of trucking 8.6 tons to e customer's fuel pile. Thus, when energy chips ach a value of $33 per ton, a farm woods worker tting fuel chips might pocket $100 per day with ry low capital investment.

Intermediate between the low-investment con- pt of figure 6 and the high-investment system own in figure 4, are several arrangements where- tractor-powered chippers operate along strip ads. Trees are dragged from distances of about 0 feet to the chippers by light winches, or small actors. If strip roads can be spaced closely (e.g., 0 feet apart), long-reach sliding-boom cranes can ip the trees after felling, draw them to the strip ad, and feed them into moderately powered ippers. Chips can be blown into pallets or quick- mp bins for forwarding to highway trucks. These andinavian systems are further described by lsson (1978), Kalaja (1978), Hakkila (1978), and akkila et al. (1979).

EXTRACT SAWLOGS AT THE STUMP— BUNCH AND FORWARD BRANCHES

When logging hardwood timber that is of quality od enough to contain sawlogs or veneer logs, is usual practice to sever the crowns from the ms and leave them near the stump as logging sh. If the massive crowns are then skidded to adside chipper, they can cause much damage to idual trees. Moreover, the heavy limbs of many ecies are so inflexible that they must be notched chainsaw before they can be compressed for pping by the feedrolls of a roadside chipper g. 7). Such notching is hard work and dangerous.

A mechanized alternative procedure was proposed by Mattson et al. (1978). By this system, crowns too massive for the whole-tree chipper would be severed from the felled and bunched tree. After the stemwood is skidded away, a small, highly maneuverable, hydraulically actuated shear mounted on a knuckle boom of a vehicle (fig. 8) would sever large protruding limbs and align them with the butt of the main stem of the top. Thus compacted, the top is grapple skidded to the wholetree chipper. In 1978, the cost per green ton to shear and compact the tops, skid them to roadslide, and chip them was estimated at $6.32 per ton, green basis.

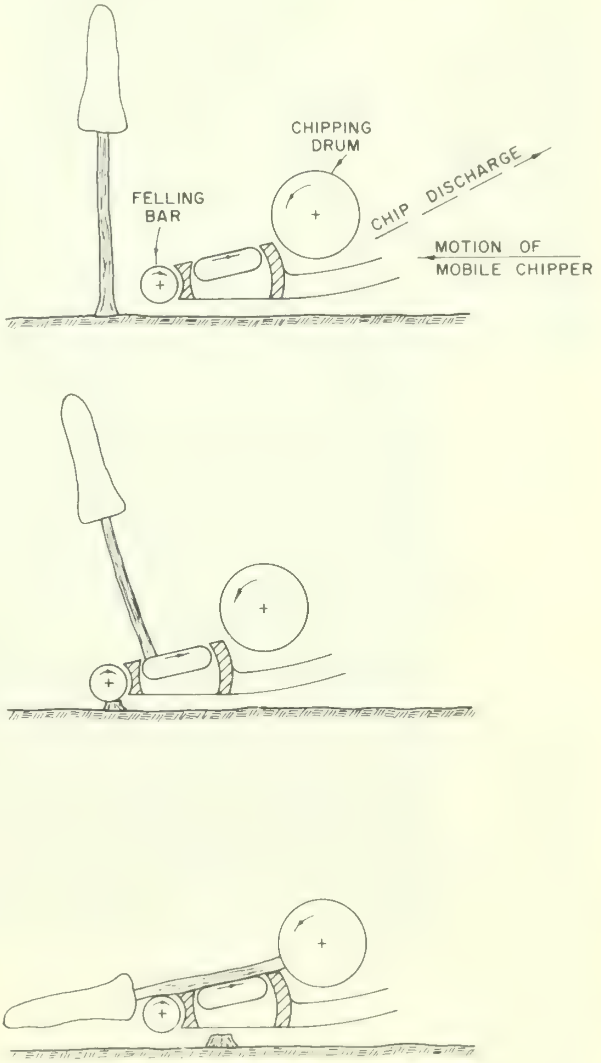


Figure 3.—*Concept of a mobile machine with a felling bar arranged to feed a drum chipper. (Drawing after Koch and Savage 1980.)*

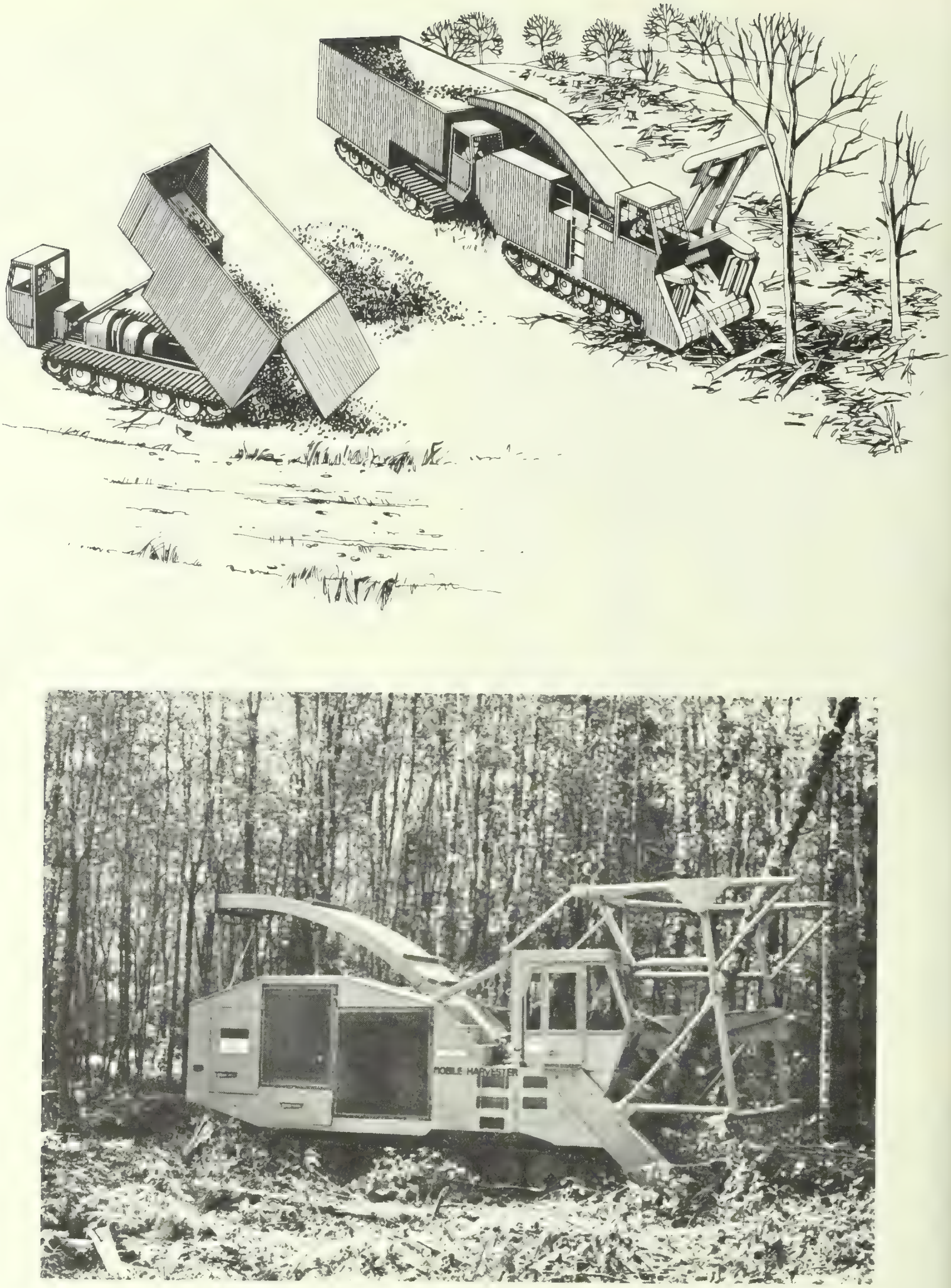
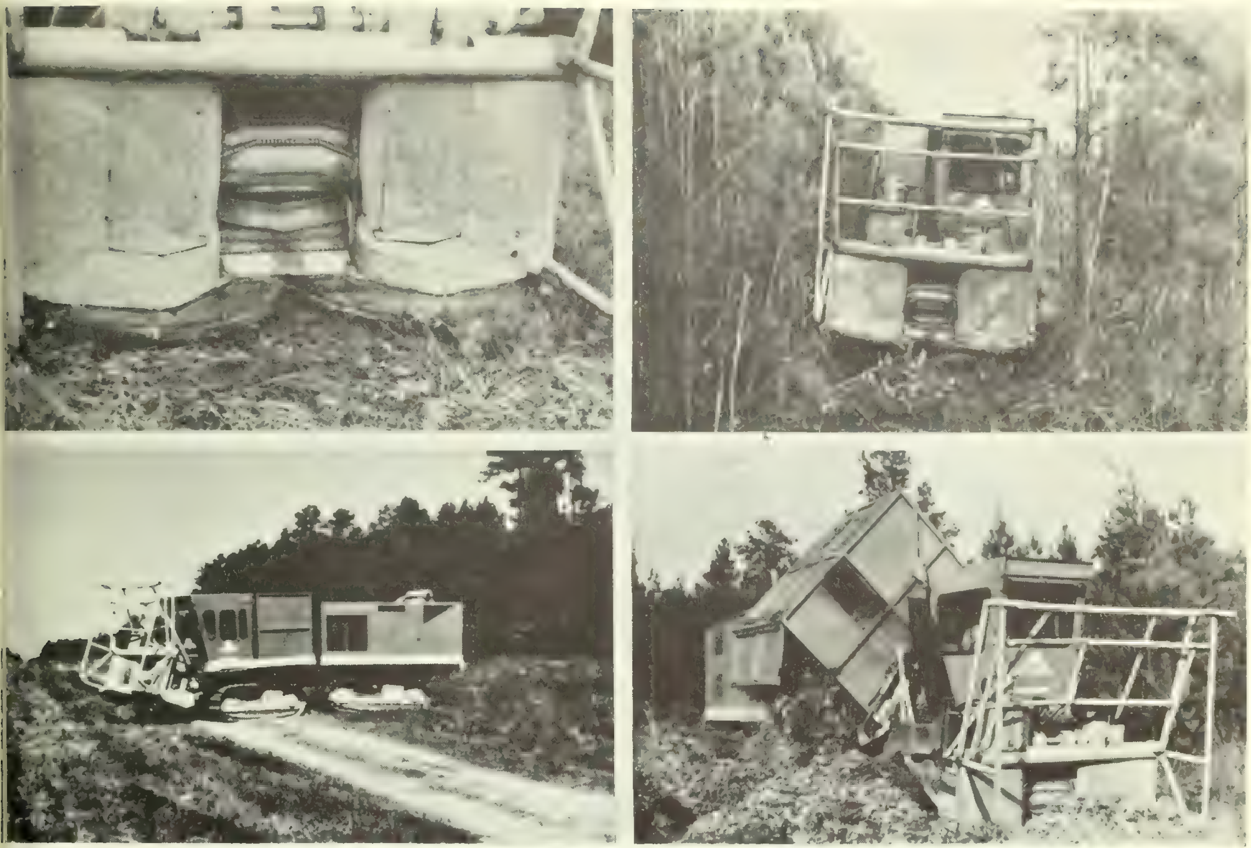


Figure 4.—*(Top) Mobile chipper and companion chip forwarders retrieve standing trees and logging slash as chips and deposit them in roadside inventory piles. (Drawing after Koch and Nicholson 1978.) (Bottom) Swathe-felling and chipping hardwoods while traveling 1 mile per hour.*



gure 5.—*NFI/GP brush harvester. (Top left) Twin counter-rotating cutting disks that sever stems just about ground level and direct them into feed rolls leading to a drum chipper. (Top right) Front view from cleared swathe. (Lower left) Side view; grillwork on the front directs falling trees forward. The chip bin is directly behind operator's cab and the power unit trails. (Lower right) Chip bin self-dumps at roadside. (Photos from J. O'Dair, NFI.)*

CHIP WHOLE TREES AT THE LANDING

In a typical whole-tree chipping operation (fig. , an investment of about $600,000 is required (979 basis). Equipment needs include a mobile adside chipper capable of chipping whole hardood trees with crowns attached, two fellernchers, and two grapple skidders. Also needed e a fifth-wheel tractor for spotting setout trailers i the woods, two fifth-wheel mainhaul tractors fr highway transport, seven chip vans, and suprt equipment for maintenance. Such operations quire 8-man to 10-man crews, producing about 0 cords weekly, or 8 cords per man-day (Warren d Kluender 1978). Recent studies of such operatns on pine-site hardwoods indicate a cost of out $15 per green ton of chips delivered to the ll, before addition of profit on investment.

EXTRACT SAWLOGS AT LANDING— THEN CHIP, CHUNK, OR BALE BRANCHES

Sawlogs and veneer bolts are removed prior to some whole-tree chipping operations in which the unmerchantable tops and all remaining standing stems larger than 3 or 4 inches are brought to a landing for chipping. In others, sawlogs or veneer bolts are separated at the landing with the remainder being chipped. Studies in the North Central states indicate that a minimum of about 10 tons (green basis) of hardwood sawlogs must be obtainable per acre to justify sawlog sorting prior to whole-tree chipping (USDA Forest Service, North Central Forest Experiment Station 1978, p. 55). Graves et al. (1977) concluded that sawlog and veneer log sorting was economical if the value of such roundwood exceeds $26 to $40 per cord at the landing, depending on the system used.

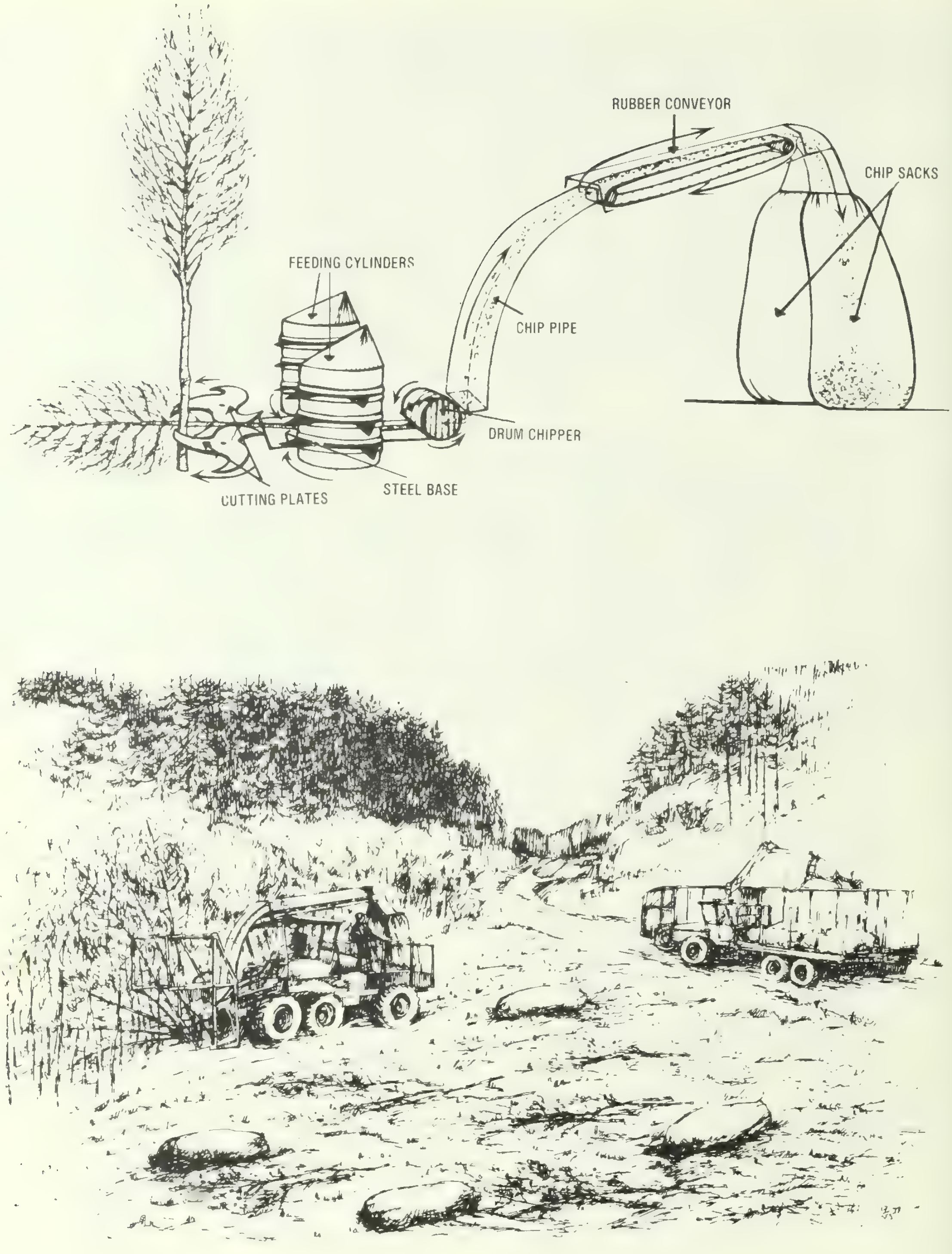


Figure 5A.—*Pallari swathe harvester. (Top) Principle of operation. (Bottom) Harvester in action, temporary chip storage in sacks, sack forwarder, and roadside discharge of sacks into a chip trailer. (Drawings from Hakkila and Kalaja 1980.)*

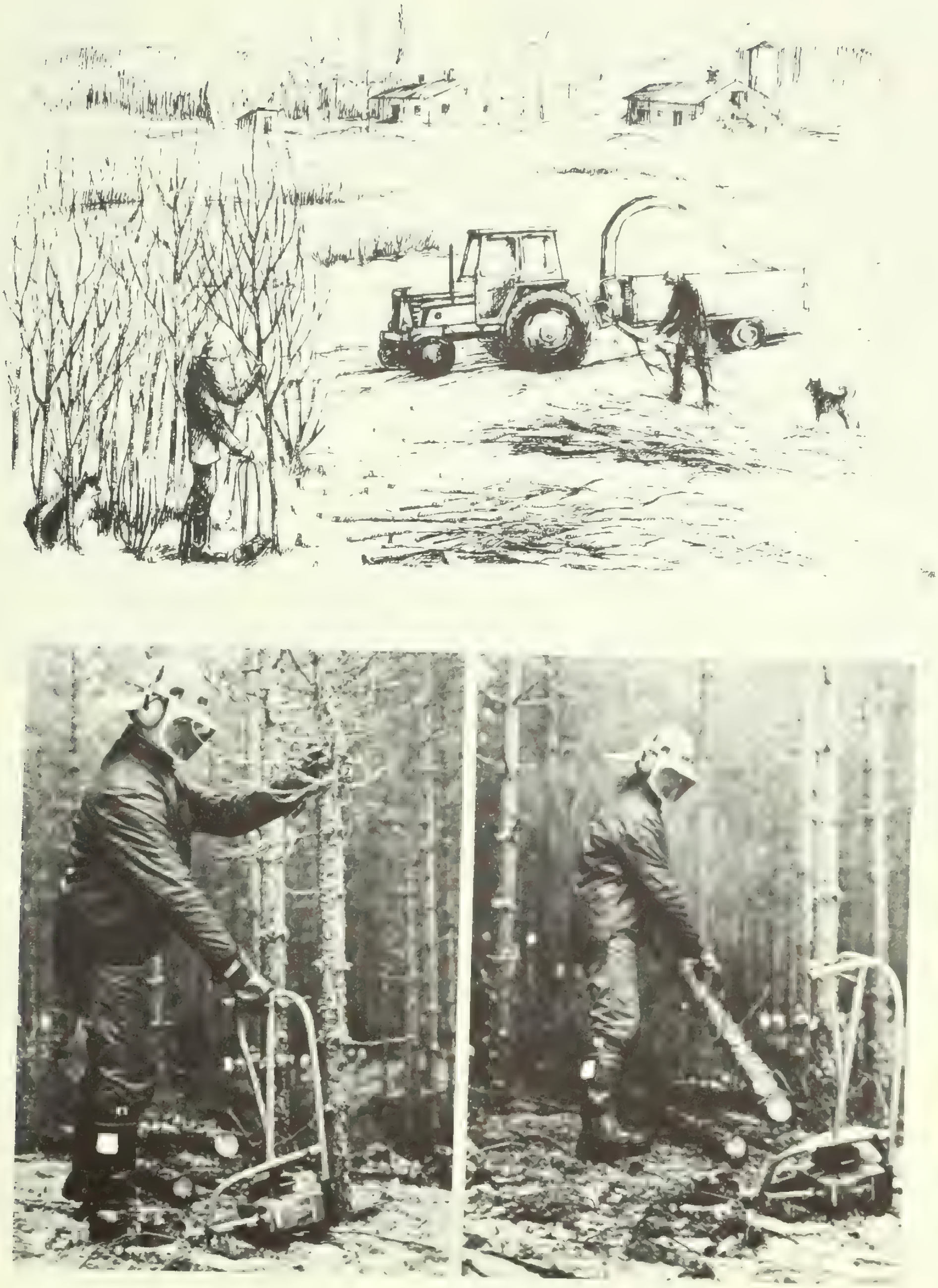
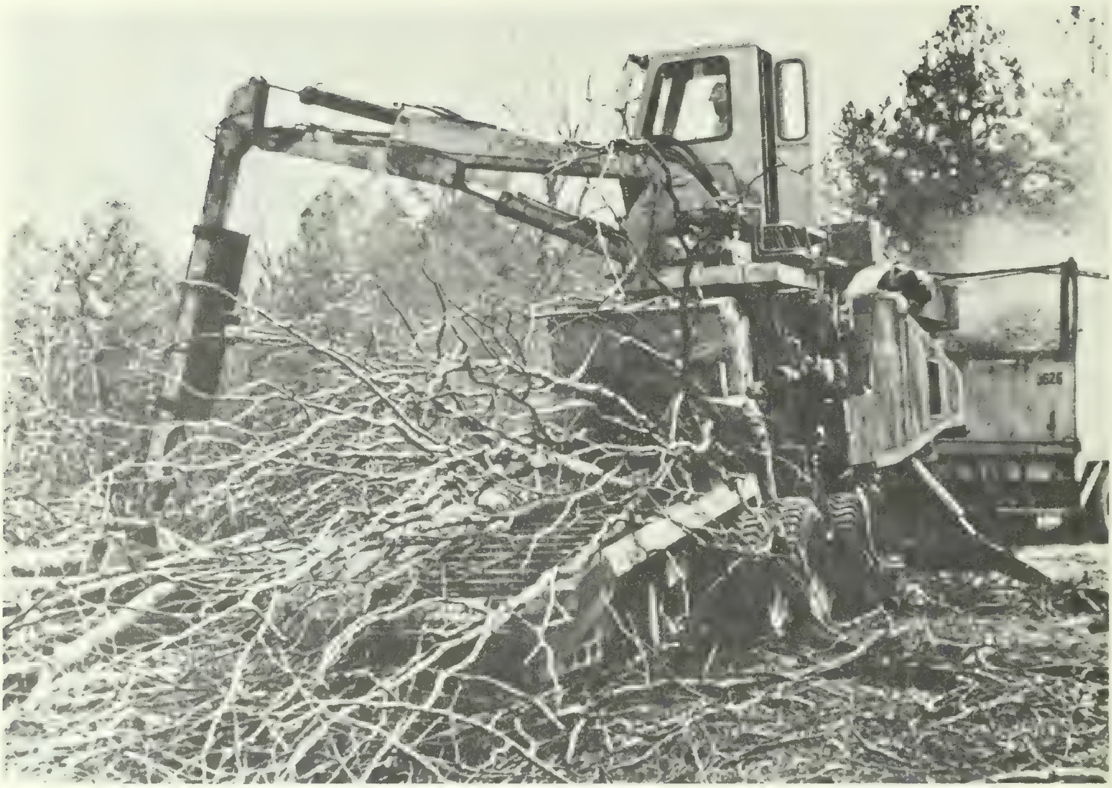


Figure 6.—*(Top) Two-man team harvesting whole-tree chips for fuel using a chainsaw equipped with a felling frame (to avoid stoop labor), and a light farm tractor powering a brush chipper. Daily output is 8 to 9 tons (green basis) for the two-man team. (Drawing after Hakkila et al. 1979). (Bottom left) Felling a small tree with a frame-mounted chainsaw. (Bottom right) Manual bunching of trees. (Photos from files of P. Hakkila.)*



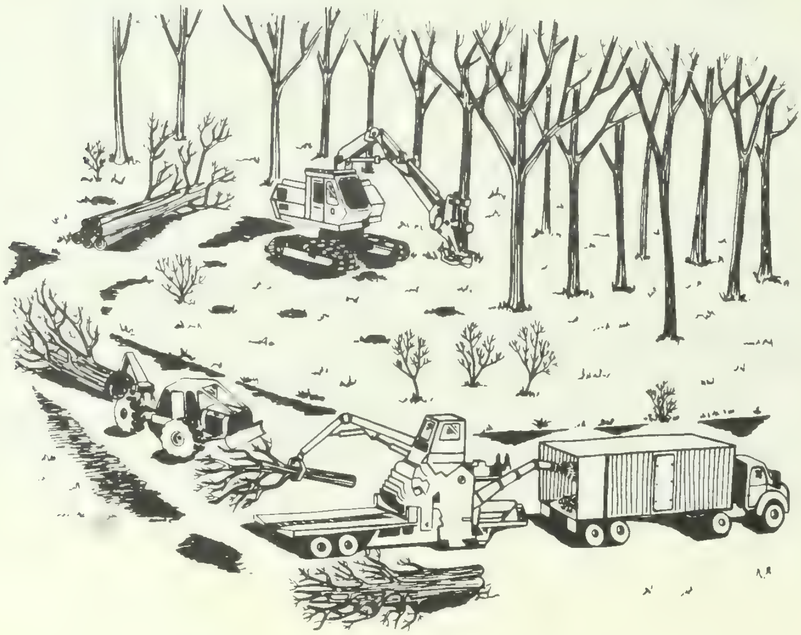


Figure 7.—*(Top) Self-feeding, whole-tree chipper at roadside landing processing pine-site hardwoods. The machine carries a 575-horsepower diesel engine and can continuously chip white oak stems 11 inches in diameter. Stem to 22 inches in diameter can be chipped with intermittent feed. Chips are blown into vans for transport to the mill. (Photo from Nicholson Manufacturing Company.) (Bottom) Typical whole-tree chipping system (Drawing after Biltonen et al. 1976.)*

Figure 9 shows a running skyline yarder teamed vith a whole tree chipper in a major operation iarvesting hardwoods from the steep hills of the irginias. With this system, whole trees are leposited on the landing, and high grade logs are emoved by chainsaw before the loader feeds emaining tops and stems into the whole-tree chiper, thus clearing the landing. Landings are bullozed to accommodate the yarder, the chipper, two hip vans, two skidders, and a log truck.

Ordinarily clearcuts are 40 acres or less. Typially, the yarder is moved twice in a 40-acre set hile the tractor that anchors the tail of the kyline (downhill or uphill, and about 800 feet away om the yarder) is moved 12 to 15 times. Virtually very tree, regardless of size, is dropped and skidded om the set. Production averages 200 tons of hole-tree chips per 8-hour day; another 15 tons ave the landing daily in the form of sawlogs. xcluding the logging supervisor, 11 men make up ie crew. Three work under the carriage (a rigger nd two choker setters), two operate chainsaws, ne runs the yarder, and one operates the chipper. ne man switches chip trailers, another unhooks hokers at the landing, and two men operate ibber-tired skidders. Additionally, a mechanic is vailable on call. Saw logs diverted from the hipper and chip vans are hauled by an independent perator (Pulpwood Production and Saw Mill ogging 1973).

Some operators find it difficult to work machines their capacities in such a continuous-flow gging operation. They therefore yard stems into ld decks; at a later date a grapple skidder eds the whole-tree chipper from the cold deck.

Mechanized machines for delimbing and log covery.—The job of delimbing hardwood trees d extracting saw logs with a chainsaw (fig. 9) is rd, dangerous work. Highly mechanized roadle machines for delimbing and dismembering rdwoods are not yet available, but something e the Hahn harvester (Larson 1978), with added rovision to sever limbs into chunks, is envisioned g. 10). The chunks would later be chipped for eergy wood at a central location.

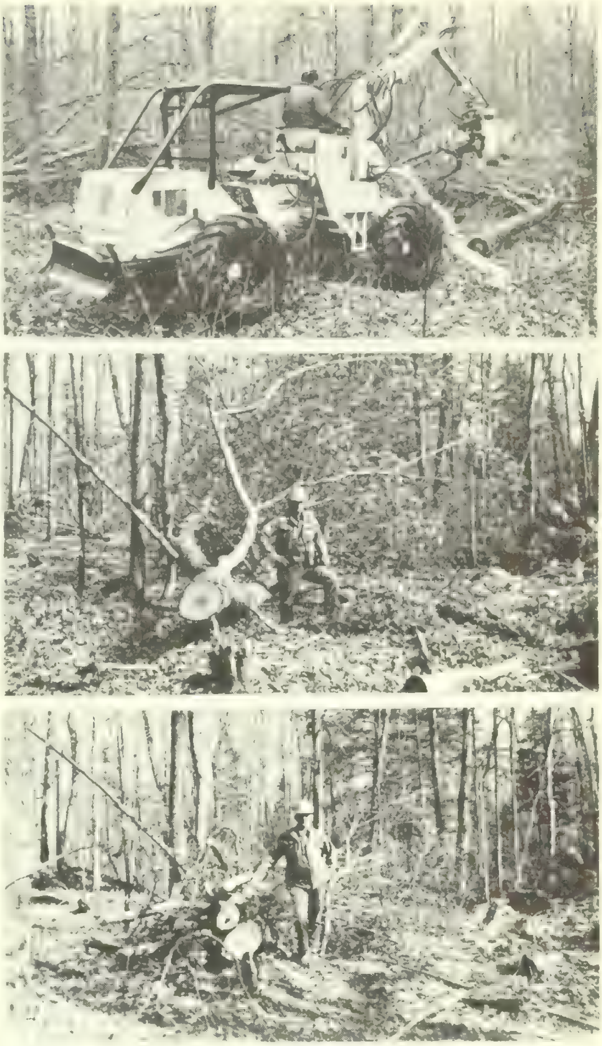


Figure 8.—*(Top) Experimental topwood harvester shearing and aligning limbs of hardwood tops. (Center) Typical hardwood top. (Bottom) Compacted top. (Photo from Mattson et al. 1978.)*

Swathe-cutting feller-buncher teamed with a log-sparation and branch baling operation.—Feller-bnchers in wide use shear one stem at a time ad accumulate several stems before dropping tem to the ground. For small stems, however, tis is slow (i.e., up to about 120 stems per hour) bcause the shearing head must approach each tree idividually. Needed is a practical machine for pine-site hardwoods and brush that will cut a swathe about 8 feet wide, severing at ground level everything in its path, while holding the severed trees to accumulate a suitable load for the grapple skidder. Conifers, with small crowns, afford easier solution than do the wide-crowned hardwoods. At least two prototypes have been built to test this idea on conifers—the Prince Albert Pulpwood machine (Stock 1978) and the Hydro-Ax swathcutter (Davidson 1978). Both use thick circular saws to sever all stems at groundline in a swathe several feet wide while the machine travels at 1 mile per hour or faster and accumulates a dozen or more severed trees before dropping them in a bunch. The Hydro-Ax has cut and bunched more than four trees per minute; in dense stands of very small spruce and fir the Prince Albert Pulpwood machine has averaged 25 trees per minute.

The rationale for development of a swathe-cutting feller-buncher is clear; its practical execution in a form appropriate for heavy-crowned small hardwoods is difficult, but probably not impossible. Assuming that resulting bunches can be ground skidded (or skyline yarded free of the ground) to roadside, they could then be separated at roadside into components to maximize value. Removal of stiff, strong limbs from multiple stems of hardwoods is a very difficult job, however. Assuming that this step can be accomplished, Walbridge and Stuart (1978) concluded that it should be possible to bale limbs and tops, and have proposed some prototype machinery (Stuart and Walbridge 1976, Stuart et al.[2], Stuart et al. 1980). Whole trees would be skidded to the landing, and left alongside the loader-baler machine where they would be delimbed and topped. The loader would not only load merchantable stems onto logging trucks, but would feed limbs and tops into a baler located beneath the loader (fig. 11).

Bales would measure about 3 feet square in end section and 3 or 4 feet long; with bulk density of 40 to 45 pounds per cubic foot, bales should weigh 1,500 to 1,800 pounds. The baler is estimated to cost $30,000 to $50,000 (1979 basis).

An experimental baler, built by International Baler Corporation, Jacksonville, Florida, was delivered to Tidewater Manufacturing Company in Brunswick, Georgia, for trailer mounting with power unit and hydraulic system and controls. The baler then was delivered to Virginia Polytechnic Institute in the fall of 1980 for evaluation. About 150 bales have been produced to date from both green and dry hardwod residues. Development work is continuing and will concentrate on devising an automatic infeed mechanism, tying procedures, and methods to increase production.

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[2] Stuart, W. B., R. G. Oderwald, J. N. Perumpral, and R. Williams. 1979. The development of engineering criteria for an in-woods baler. Final Report, USDA Forest Service, Contract 333927-1, March 16, 1979.

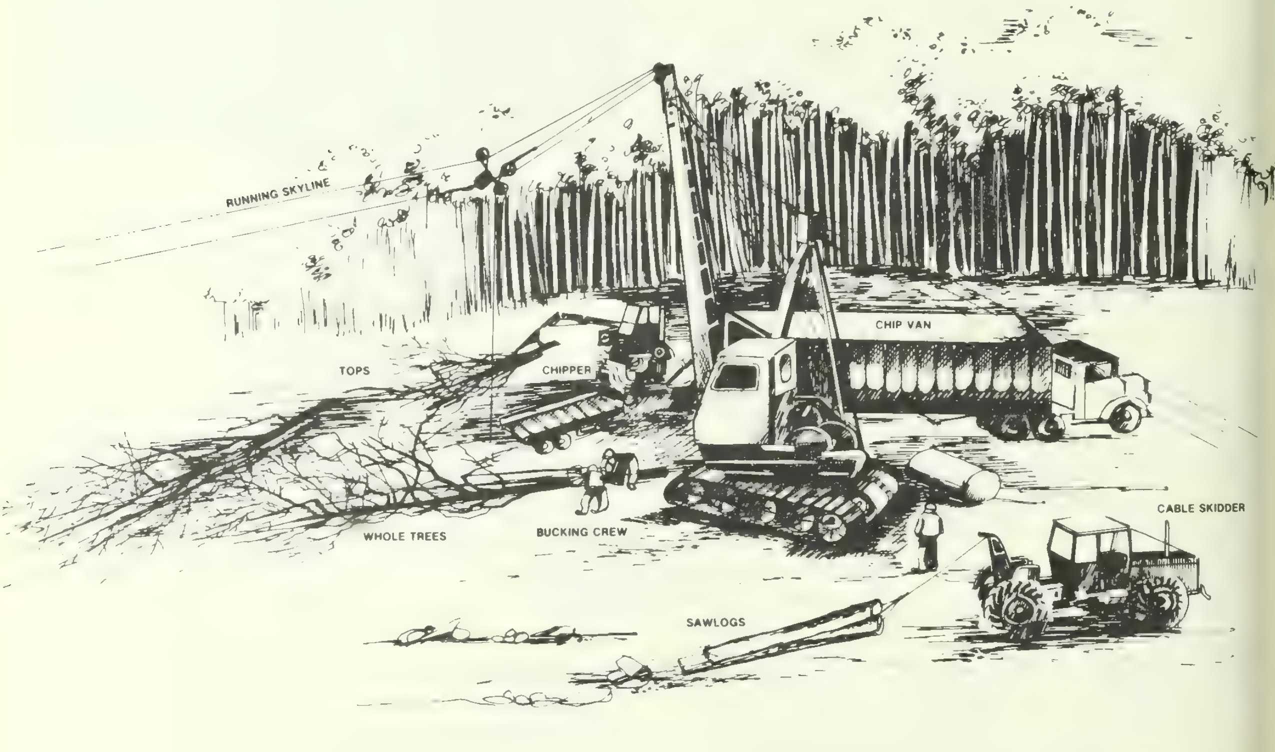


Figure 9.—*In this West Virginia operation on steep terrain, a running skyline yards entire hardwood trees to the landing, where chokers are released. Sawlogs of high quality are extracted by chainsaw. The loader feeds tops to the whole-tree chipper which blows resultant chips into a waiting van. (Drawing after photo from Westvaco Corporation.)*

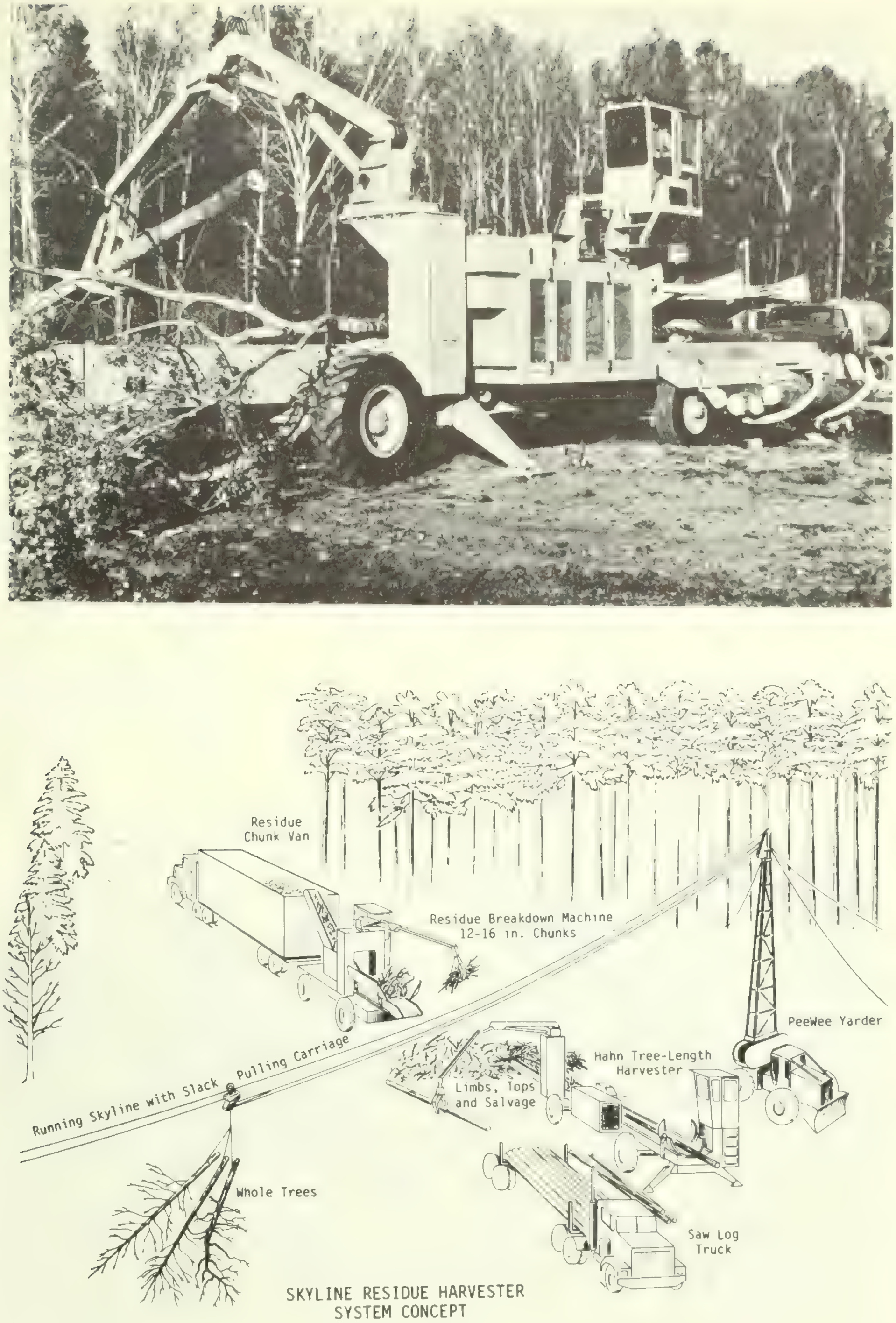

Residue Chunk Van
Residue Breakdown Machine 12-16 in. Chunks
PeeWee Yarder
Running Skyline with Slack Pulling Carriage
Hahn Tree-Length Harvester
Limbs, Tops and Salvage
Whole Trees
Saw Log Truck
SKYLINE RESIDUE HARVESTER SYSTEM CONCEPT

Figure 10.—*(Top) Hahn harvester shear-delimbing aspen*(Populus tremuloides *Michx.)and sawing stems into logs or bolts. Machine functions are powered by a 160-hp diesel engine. The harvester is roadable and can process about 840 stems per 8-hour shift. (Photo from Hahn Machinery, Inc. Two Harbors, Minn.). (Bottom) Layout combining the Hahn harvester with a running skyline and, in a secondary operation, reducing limbs to chunks for highway transport. These chunks would later be chipped for fuel or fiber. (Drawing from a proposal by the Pacific Northwest Forest and Range Experiment Station, USDA Forest Service.)*

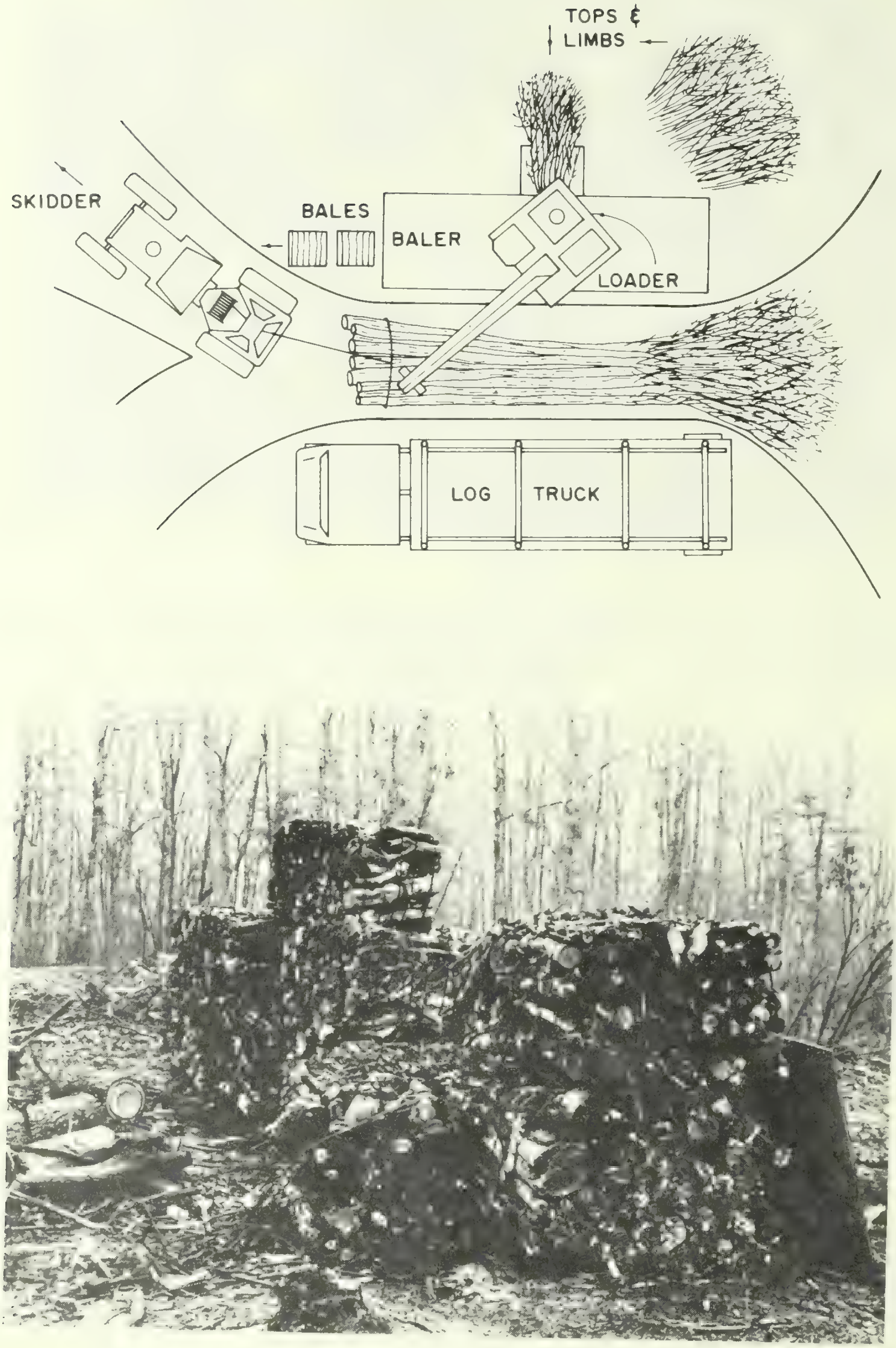


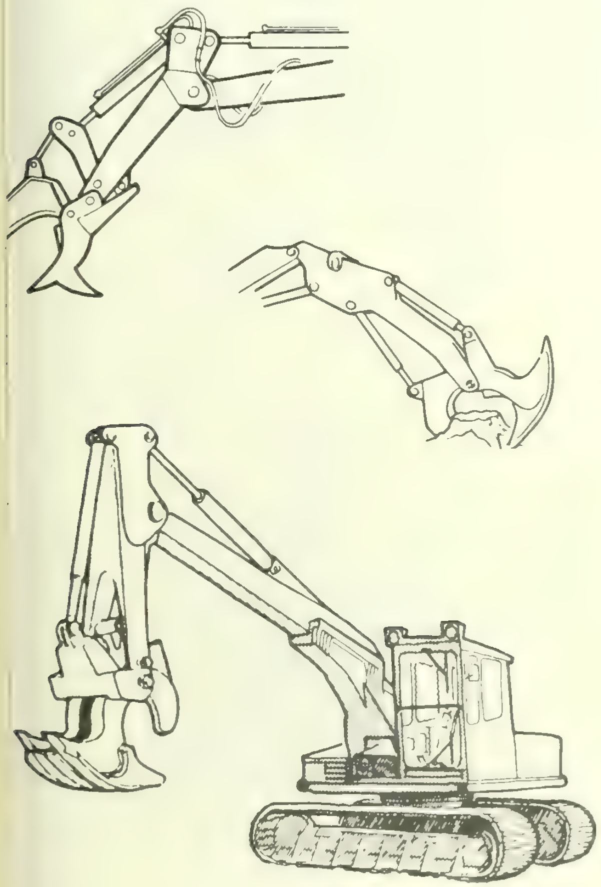
Figure 11.—*Concept for recovery of sawlogs followed by baling tops and limbs at the landing. (Top) Layout of landing where stems are delimbed, topped, and loaded on trucks; limbs are loader-fed, sheared to short lengths, and baled. (Bottom) Cubical bales are strapped with 10-gauge annealed wire, measure about 3 feet on a side, and weigh 1,500 to 1,800 pounds when green. (Drawing after Walbridge and Stuart 1978; photo from T. A. Walbridge, Jr.)*

CHIP RESIDUES—INCLUDING STUMP-ROOT SYSTEMS—AT THE MILL

As described in figures 10 and 11, it is possible to deliver tops and branches in the form of chunks or bales to an energy-producing plant where they can be chipped in a centralized facility.

Stump-root systems can also be extracted from the ground following primary harvest operations, and delivered to a central plant for chipping.

Stump pulling and processing.—Proponents of complete-tree utilization view the central stump-root system of pine-site hardwoods as a major source of wood for energy or fiber. These central stump-root systems, with lateral roots severed at a 1-foot radius, comprise about 15 percent of the weight of above- and below-ground tree biomass (ovendry basis) and about 28 percent of the weight of bark-free merchantable stems of small pine-site hardwoods. Ready availability of an unused wood resource of such magnitude is a strong incentive to devise practical stump harvesting methods. Moreover, removal of stumps in a commercial harvesting operation substantially reduces the cost of preparing the site for subsequent planting. Stump removal is not a new art. There were about 500 kinds of stump pullers on the American market in the 1800's, and stump pulling became a common American profession; two men with a yoke of oxen and a stump puller could travel indefinitely across the country pulling 20 to 50 stumps per day at $0.25 per stump—the standard price in 1850 (Sloan 1958).



igure 12.—*The Pallari stump harvester. (Top) Two designs of splitter-grapple head. (Bottom) Mounted on an excavator tracked chassis. (Drawing after Andersson et al. 1978.)*

Today, many entomologists, hydrologists, and soil scientists in the South view harvest of central stump-root systems with favor, because of diminished insect attraction to freshly exposed stump surfaces, improved percolation of water into many soils, and improvement of structure of some soils by the same mechanism as plowing of agricultural land. Uprooting is not unique to man-made forests; as noted by Stephens (1956), trees of the "primeval forest" had two general destinies: uprooting, or piece-by-piece disintegration in place.

Andersson et al. (1978) and Walker (1976) have reviewed equipment available worldwide to pull stumps after trees have been felled. Major machines for this purpose include:

Machine	**Reference**
Pallari stump harvester	Hakkila and Makela (1973, 1974)
Cranab stump harvester	Andersson et al. (1978)
Dynapac stump harvester	Andersson et al. (1978)
OSA stump harvester	Andersson et al. (1978)
Wick-Bartlet stump harvester	Harrison (1975)
Rockland roto lifter	Walker (1976)
Cavaceppi stump auger	FAO (1962)
STFI oscillating saw	Andersson (1975)
FLECO stump blade	USDA Forest Service (1971)
Bulldozer-mounted root rake	USDA Forest Service (1971)
Foster vibro stump extractor	Anonymous (1978)

The Pallari stump harvester appears well adapted to harvesting stumps of pine-site hardwoods. Several versions of the machine were designed in Finland in 1975-1977 (fig. 12). The unit is generally mounted on an excavator-type crawler tractor, but tests have also been made on a feller-buncher chassis. Andersson et al. (1978) note that the machine, which is simple and reliable, can pull individual stumps and split them to the desired degrees of fragmentation. Blomqvist (1978) reported that, in commercial practice, the Pallari stump harvester produces 6.4 cubic meters (loose-wood basis) per hour and that cost of rootwood so harvested is $8.40 per cubic meter (loose-wood basis) delivered to the mill; transport distance to this mill averages about 25 miles.

The OSA 635 prototype stump harvester also appears to have some potential for pine-site hardwoods. The machine consists of a frame, a falling weight, and four movable knives. The falling weight drives the knives into the stump, splitting it in a cruciform pattern (fig. 13 top). This operation also frees the stump. When mounted on a feller-buncher or excavator chassis, grapple claws (fig. 13 bottom) fitted to the splitter can split, lift, and load stumps at a rate of about 5 cubic meters of solid wood per hour (Andersson et al. 1978). These authors propose three systems to deliver stumpwood at three levels of cleanliness into trucks for highway transport to the mill; each is based on initial splitting, harvesting, and limited fragmentation of stumps, with subsequent processing as follows:

System description	**Cost, delivered 60 miles to mill (solid wood basis)**
	Dollars/cubic meter
Uncleaned wood	28.52
Partial cleaning of wood accomplished in the forwarder in transit to roadside	28.75
Intensive cleaning by hammermilling and screening at the landing before loading into trucks	32.43

Users of rootwood prefer it cleaned of dirt and rocks at time of harvest. To satisfy this need, the L. B. Foster Company, Pittsburgh, Pa., combined a vibrating grapple head with a hydraulic self-propelled loader in a prototype stump harvester (fig. 14). To pull and bunch a stump, the operator lowers the open grapple over the stump, with prongs rotated to avoid visible outstretched roots
Hydraulic pistons close the grapple prongs unde
the root system and the vibrator is started. Th
loader crane raises the grapple and extracts th
stump-root system. Excess dirt is shaken off a
the operator swings the vibrating stump-root t
the bunching area, where it is dropped when clean
This cycle, as observed in experimental runs, take
90 seconds or less. A grapple sized to pull 24-inc
stumps weighs 3,000 pounds (Anonymous 1978).

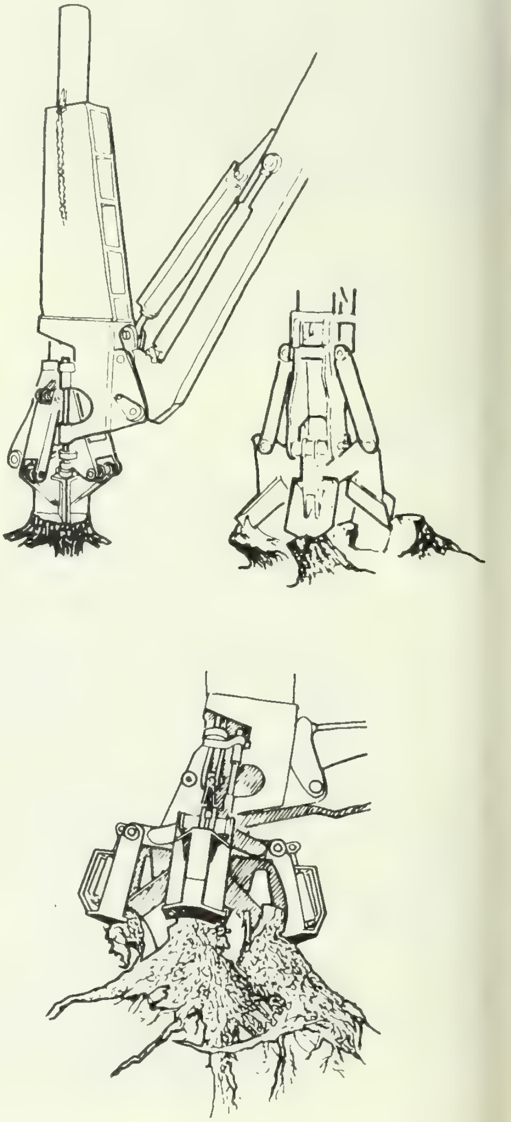


Figure 13.—*ÖSA stump harvester. (Top) Splitter. (Bottom Splitter compined with a grapple for mounting on a feller-buncher chassis. (Drawing after Andersson et al. 1978.)*

igure 14—*Stump puller incorporating vibration device—just above grapple—to free stump from ground and loosen dirt from it. (Left) Grapple closing over stump. (Right) Extracted stump-root system. (Photos from L. B. Foster Company.)*

TRANSPORT COMPLETE TREES TO THE MILL

Whole trees, severed near ground level, can be unched and loaded for transport, entire, to a entralized chipping plant at the energy-producing lant (figs. 15 and 16 top). Complete trees, with entral root portions intact, can also be harvested nd transported entire.

Tree puller-bunchers.—Most pine-site hardwood ees are small in diameter and not very heavy. 6-inch southern red oak, for example, complete ith crown and lateral roots to a 1-foot radius, eighs about 430 pounds—of which about 16 perent is in the stump-root system. Costs per ton for onventional felling and bunching are inversely roportional to the weight of the tree sections omprising the bunch. Harvesting the central ump-root system with the stem maximizes weight er section and should improve efficiency.

Two tree pullers potentially practical for southern forest operations have been invented. One pulls trees including entire lateral root systems, which are subsequently sheared and left on the ground. It has the advantage of an adjustable-diameter shear to accommodate trees of varying diameters (Sederholm 1976). This machine is not further discussed because no data are available on its operation on hardwoods, for which pulling forces with lateral roots intact are very large.

The second machine, jointly developed by the Southern Forest Experiment Station of the USDA Forest Service and Rome Industries (Koch 1976), leaves lateral roots in place in the soil; only the central stump-root system is harvested. Machines of this design are in steady commercial operation in Florida pulling and bunching 45 to 90 small southern pines (to 12 inches dbh) per hour. Harvesting costs, including profit on equipment investment, total about $8.61 per green ton delivered in tree lengths to the kraft mill where both rootwood

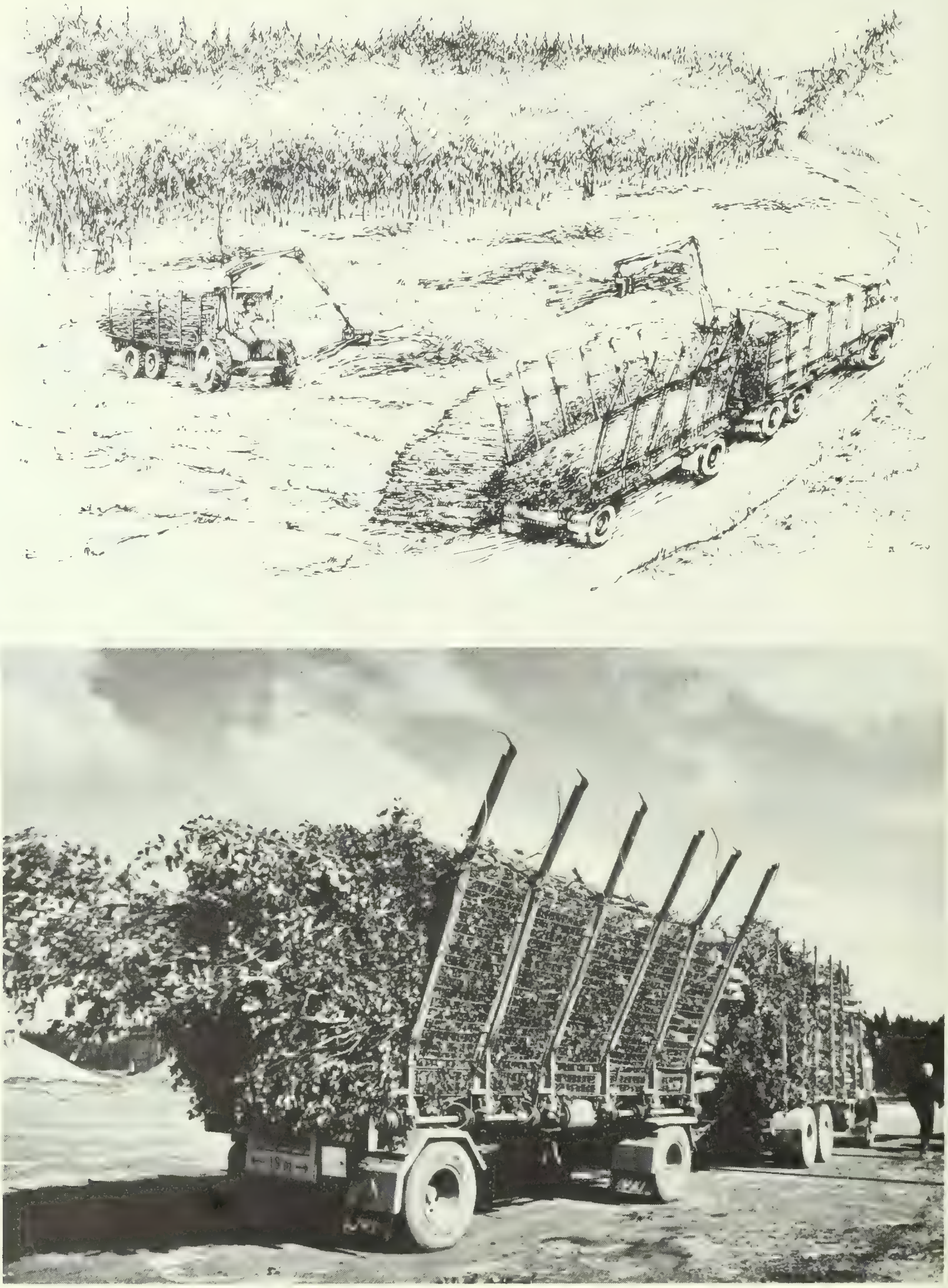


Figure 15.—*Harvest and transport of small whole trees to centralized chipping plant. (Top) Trees chain-saw felled and bunched as in figure 6, grapple loaded on forwarder, and reloaded at roadside on truck with bunk posts rigged to compress the load. (Drawing after Hakkila et al. 1979.) (Bottom) Whole-tree portions of speckled alder* (Alnus incana *(L.) Moench) loaded onto a trailer rigged to compress the load and contain it within legal space. (Photo from Yhteisostot Oy Jyki Tehtaat, Finland.)*

nd stemwood are drum debarked and converted o pulp chips (Koch 1977). En route to the mill, rucks carrying the tree-length limb-free stems with taproots attached) pass through a washing tation consisting of two fire-hose nozzles swivel-ounted atop 6-foot stands, one on each side of concrete slab. As each truck passes through the tation, the driver washes his load; total delay me is 25 to 30 minutes per load (Davis and urley 1978).

Grillot and McDermid (1977) found that in pine tands in west Florida, productivity of the machine hen making clear cuts was 16 cords per machine-our; when thinning it was less productive, averagg only 7 cords per hour because of the smaller verage size of trees.

The tree puller, manufactured by Rome Indusies, Cedartown, Ga., can be fitted through a quick-itch mechanism on a number of prime movers—for xample, a Caterpillar 920 or a John Deere 544B igs. 1 and 17). Two elements are essential to e design (fig. 18). The first is a scissors-type rip achieved with a pair of stout horizontal knife ades that close at groundline and bite several ches into the stem from opposite sides.

With this grip anchor, the second element in the esign comes into action. It is a clamshell-hinged bular shear, 22 inches in diameter and made of -inch-thick steel. The shear, sharpened on the wer edge, is forced vertically into the ground a depth of 10 inches, thereby severing lateral ots all around the tree. At this point, broad eps on opposite sides of the shear strike the round and limit further penetration. An additional roke of the hydraulic cylinder raises the grips 9 ches while the steps remain pressed against the il surface. The effect is to jack the stem and break free of the ground. Finally, the complete tree lifted into the air and bunched for skidding. nce shearing takes only a few seconds, a tree can harvested and bunched in about 45 seconds.

Dirt and rocks that adhere to the stump root stem can present problems, expecially in clay ils. Hardwood stump root systems are more fficult to clean than the more compact roots of e southern pines. With pines, much dirt is shaken ee during bunching, skidding, and stacking; ashing en route to the mill dislodges more dirt, d finally a drum debarker can remove most what remains so that bark-free (and remarkly dirt-free) root wood emerges from the drum ebarker to pass through disk chippers and hence to the mill.

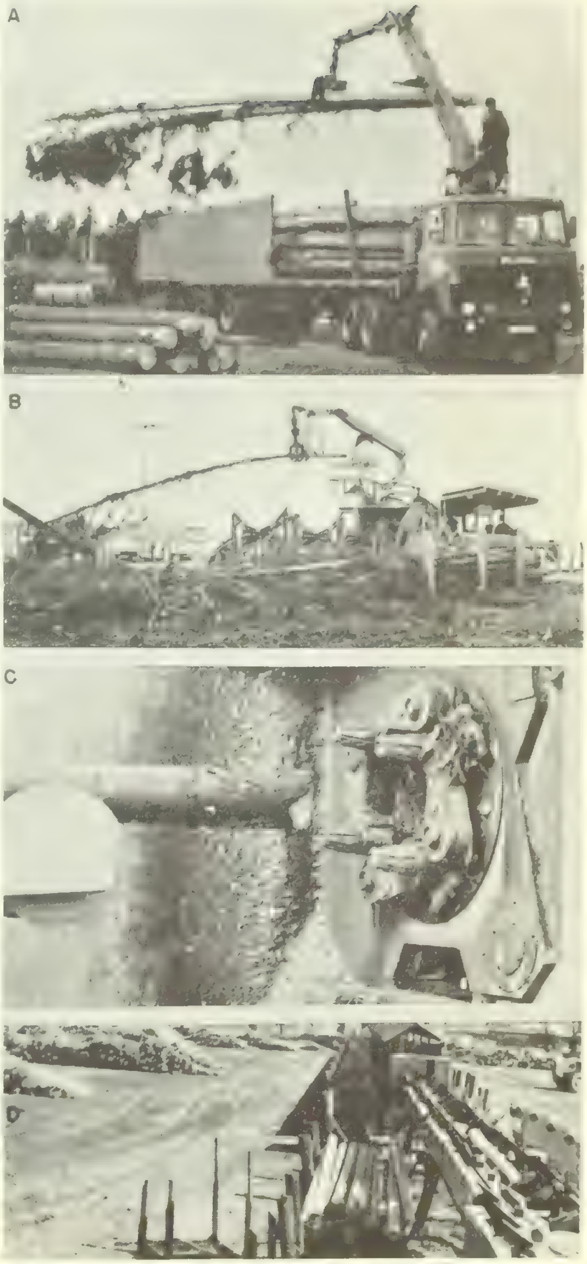


Figure 16.—*(A) Whole trees arriving at a tree merchandiser (B) Whole trees being grapple-loaded onto the infeed rolls of the delimbing machine (C) Rotating rolls equipped with knives delimb stems at 120 to 150 feet per minute; limbs are used for fuel or fiber. (D) Delimbed stems, after passing through a mechanical ring debarker, are crosscut for maximum value into poles, logs, and bolts. (Photos from Kwasnitschka 1978.)*

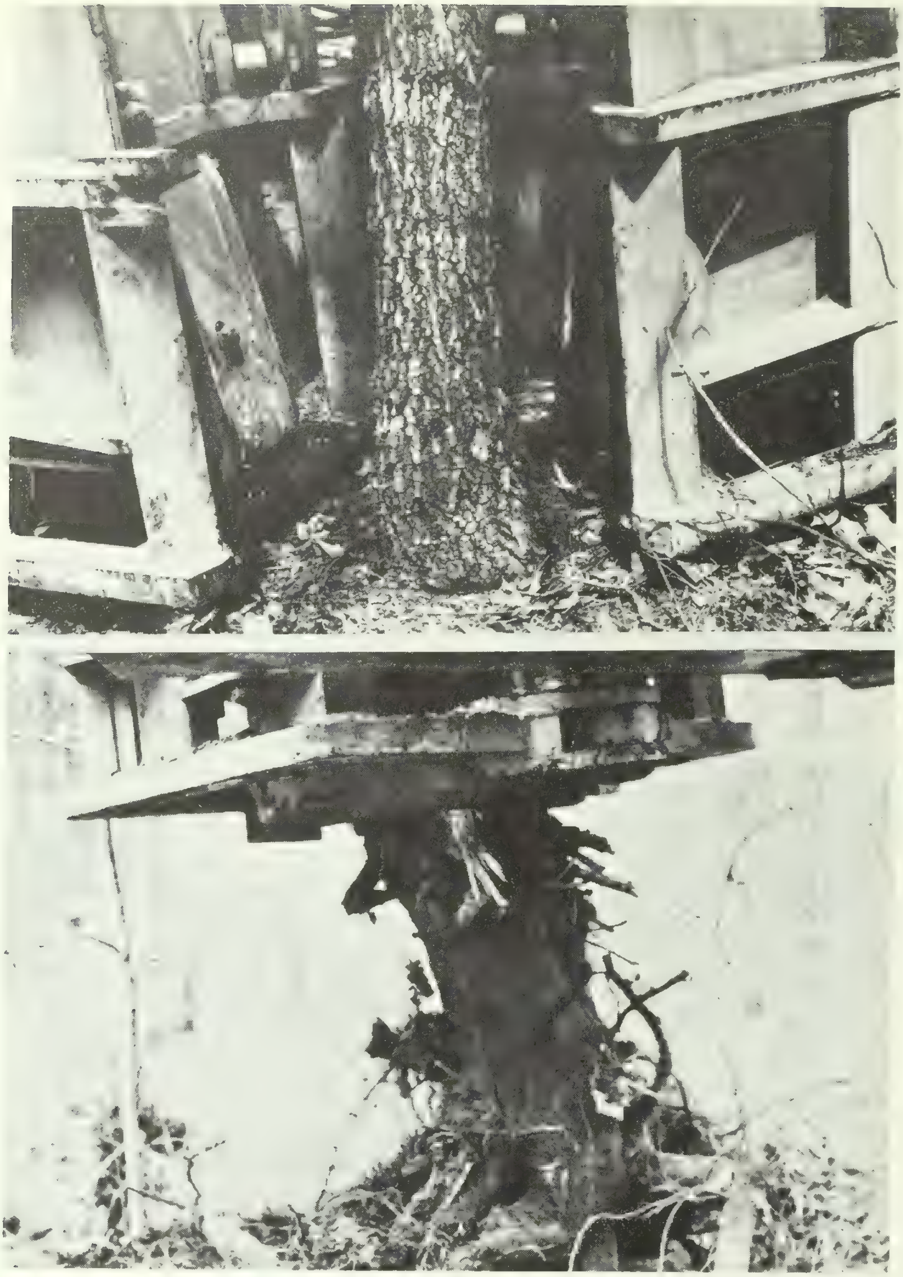


Figure 17.—*(Top) Tree puller-buncher poised to grip 8-inch southern red oak at groundline. (Bottom) Hickory tree pulled from ground after lateral roots near surface were severed, leaving central root mass intact. (Photos from D. Sirois, Southern Forest Experiment Station, Forest Service—USDA, Auburn, Ala.)*

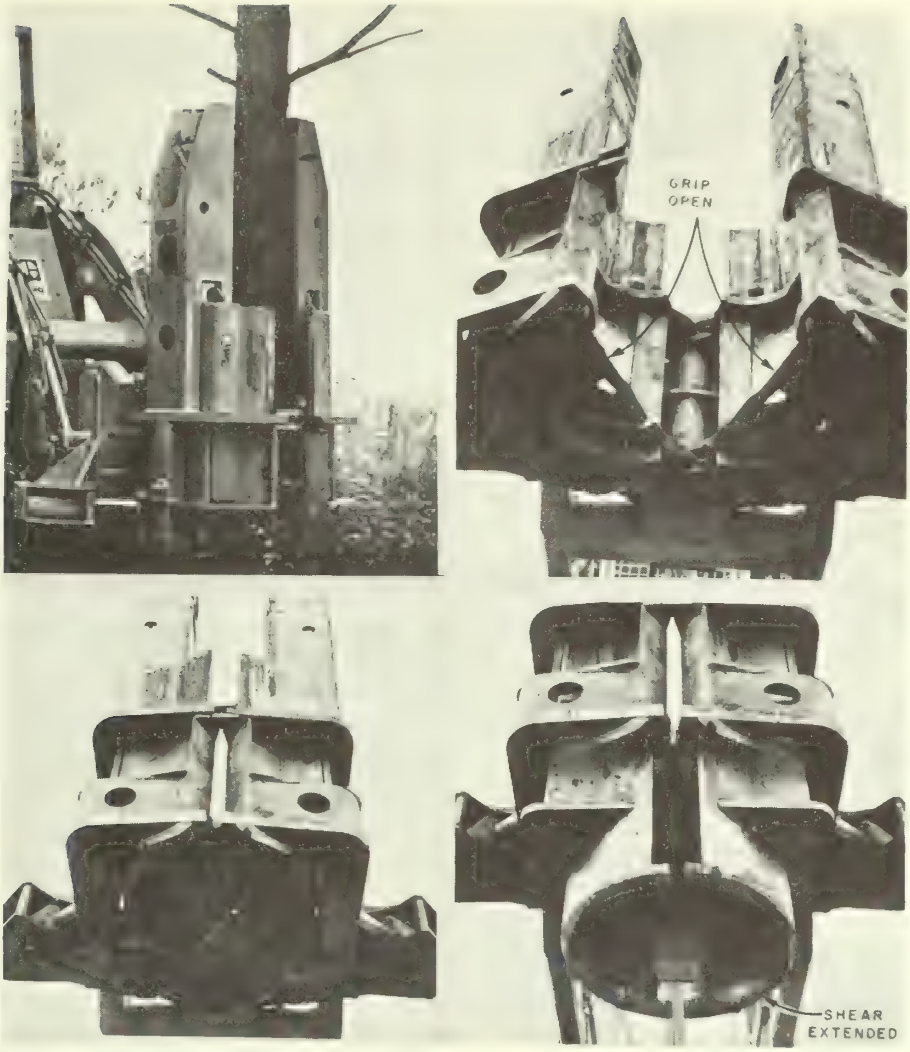


Figure 18.—*(Top left) Rome TX-1600 lateral root shear and tree puller mounted on a conventional four-wheel-drive articulated loader, with hinged grip closed on tree to be harvested. (Top right) View of gripping knives in open position with shear retracted. (Bottom left) Grip closed; in operation the knives grip the tree stem at ground level; no other grip is needed. (Bottom right) Grip closed and tubular shear fully extended 20 inches. Steps that bear against soil surfaces during last 9 inches of extension are visible on opposite outer sides of the shear tube. Each side of the tube is independently driven through its 20-inch stroke by a 6-inch hydraulic cylinder housed in the vertical column.*

Sandy sites harvested by the tree puller show few holes; dirt falls back into the cavities and leaves a hole only a few inches to a foot in depth. These holes are filled up after rains and movement of machines over them.

To provide design information for modification of the Rome lateral root shear and tree puller to adapt it for use on southern hardwoods, Sirois (1977) collected data on stump-root biomass and on forces when shearing and pulling white oak, southern red oak, hickory sp., and sweetgum. In a 75-tree sample, green weight of the central stump-root system averaged 18 percent of the complete-tree weight of above- and below-ground parts. The harvested stump-root system weighed 22 percent as much as the total above-ground biomass. Harvested portions of the stump-root system had average green weight (when cleaned) of 104 pounds, with range from 79 to 164 pounds in trees that measured from 4 to 12 inches in dbh and averaged about 6.8 inches.

Hickories were the most difficult of the four species to extract because most have taproots with deep laterals. Because the lateral root shear penetrated only 10 to 12 inches into the ground, deeper laterals were not severed and pulling forces sometimes exceeded machine capability. Forces to shear laterals were greatest for the hickories, regression relationships indicating that more than 200,000 pounds are required to drive the shear to a 10- or 12-inch depth in clay-loam soils; lifting forces were less than 70,000 pounds.

The Rome tree puller tested has shear blades 16 inches long that grip the tree at its base. Trees 12 inches in dbh of all four species may have butt diameters in excess of 16 inches, thus preventing closure of the tubular shear with resultant inability to shear laterals around the complete tree circumference; when lateral roots are not completely severed, pulling forces may be excessive.

The machine as tested weighed about 30,000 pounds when mounted on a Caterpillar 930 wheeled loader, and ground bearing pressure was about 10 psi. In soft ground the machine sometimes penetrated the vegetative mat and became stuck.

From this test series, Sirois (1977) concluded that the equipment could be made to pull pine-site hardwoods on a production basis if modified and given operational limits as follows:

- The prime mover carrying the shear head should exert less ground pressure (about 6 psi) and be capable of exerting higher drawbar forces than normal wheeled loaders.
- The depth of penetration of the lateral root shear should be increased (mainly for sweetgum and hickory).
- Additional force is needed to close the scissor blades that grip the tree at groundline, thus insuring that the tubular shear is closed around the complete circumference of the tree so that all lateral roots will be severed during its cutting stroke.
- To keep machine cost and size within reason, an upper limit on tree size should be established at about 9 inches dbh.

Centralized processing plant for complete trees.—The wood industry applies the term merchandiser to a centralized facility that dismembers tree-length logs, whole trees including crowns, or complete trees including central stump systems as well as stems and crowns.

Figure 16 illustrates the principal involved whereby tree components are separated for diversion to their highest-value use. Branches, tops, bark, and central root systems are converted into energy chips. Stems yield bark-free pulpwood, saw logs, and veneer logs.

CONCLUSION

Potentially available processes to harvest energy wood are numerous and diverse. It is difficult, however, to profitably produce energy chips from southern forest residues at a price that consuming industries are willing to pay. Including a 30-percent pretax profit on harvesting investment, the cost of energy chips delivered into mill stockpiles will likely range from $18 to $30 per ton (green-weight, 1980 basis). During the next decade, a few practical systems should evolve—but not without much trial and error.

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